ADAPTIVE DELAY TOLERANT ROUTING FOR ENHANCED CONNECTIVITY IN VEHICULAR NETWORKS

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ABSTRACT

To enhance the network performance, many researchers have proposed solutions to resolve the minimal persistence of routing protocols in urban vehicular networks. These proposals exploit basic network services and information for optimal route calculation and data delivery. Vehicular Adhoc Networks (VANETs) have distinct characteristics compared to other ad hoc network like high mobility and constrained road patterns. Therefore, it is hard to establish an end-to-end connection to transmit a packet from the source to the destination. In this context, geographic routing protocols are currently considered as the best choice for routing. Geographic routing requires each vehicle to obtain knowledge about other nodes in the network by broadcasting the HELLO beacon to the neighbours. However, it results in a heavy load being generated, which in turn leads to increased overheads, collision and contention. In VANETs, all the routing protocol consider a pre-calculated route for the dissemination of messages, but it is impractical. These problems can be mitigated by the Delay Tolerant Network (DTN). Therefore, providing a robust and adaptive routing protocol is considered as crucial for high performance in partially connected networks. Many routing techniques such as Greedy Perimeter Stateless Routing (GPSR) and Geographic Opportunistic (GeoOpps) etc. have been developed to solve those problems in partially connected vehicular networks but still have some limitations. For instance, GeoOpps route discovery is based on finding a vehicle which is driving towards the destination, though this choice is not practical. Meanwhile, existing DTN routing protocols in vehicular environment are cannot select appropriate intermediate nodes for the sparse environment. To overcome these drawbacks, a novel approach has been introduced in this research, which organizes the operation of broadcasting the HELLO beacon messages in VANETs by considering specific parameters. Each node in the network broadcasts the

HELLO beacon message based on its position, vector and predicted future direction that are acquired by the vehicle Direction Indicator Light (DIL). DIL information has been introduced for the first time in this research domain. An Adaptive Geographic DTN Routing (AGDR) protocol is proposed in vehicular networks for the urban scenario to enhance connectivity. The solution is designed for heavily partitioned environments which suffer from frequent network disconnections by proposing the most suitable intermediate node selection mechanism through a next-hop selection process. The next-hop selection process utilizes node position, current direction, speed and the predicted direction that is acquired by DIL. The performance of the proposed protocol is evaluated by NS-2 in terms of efficiency, overhead and end-to-end delay in contrast with previous work. Simulation experiments confirm the performance supremacy of AGDR compared to contemporary schemes in terms of packet delivery ratio, overhead and end-to-end delay. Simulation results demonstrate that AGDR improves the packet delivery ratio (5-7%), reduces the overhead (1-5%) and decreases the delay (0.03 to 0.05 ms). Therefore, AGDR improves route stability by reducing the frequency of route failures.

ABSTRAK

Untuk meningkatkan prestasi rangkaian, ramai penyelidik telah mencadangkan penyelesaian bagi mengurangkan protokol laluan dalam rangkaian kenderaan bandar. Cadangan-cadangan ini adalah untuk memahami secara meluas perkhidmatan rangkaian asas dan maklumat bagi pengiraan laluan dan data penghantaran optimum. Rangkaian Lalu Lintas Kenderaan yang Khusus (VANETs) mempunyai ciri-ciri yang berbeza berbanding dengan rangkaian khusus yang lain seperti pergerakan yang tinggi dan pola jalan yang terbatas. Oleh itu, adalah sukar untuk mewujudkan sambungan hujung-ke-hujung untuk penghantaran paket dari sumber ke destinasi. Dalam konteks ini, protokol laluan berdasarkan kedudukan kini dianggap sebagai pilihan terbaik untuk penghalaan. Dalam protokol ini, setiap kenderaan mendapat pengetahuan mengenai persimpangan lain dalam rangkaian yang disiarkan oleh beacon HELLO kepada penduduk setempat. Walau bagaimanapun, ia menyebabkan penghasilan bebanan berat yang seterusnya membawa kepada peningkatan kos, perlanggaran dan perdebatan. Dalam VANETs, semua protokol laluan mempertimbangkan laluan pra-pengiraan untuk menyebarkan mesej, tetapi ia adalah tidak praktikal. Masalah-masalah ini boleh dikurangkan oleh Toleransi Rangkaian Kelewatan (DTN). Oleh itu, penyediaan protokol laluan yang teguh dan bersesuaian dianggap sangat penting untuk prestasi yang tinggi dalam sebahagian rangkaian tersebut. Banyak teknik laluan seperti GPSR, GeoOpps dan lain-lain telah dibangunkan untuk menyelesaikan masalah tersebut tetapi masih mempunyai beberapa batasan. Sebagai contoh. Penemuan laluan GeoOpps adalah berdasarkan kepada pencarian kenderaan yang dipandu ke arah destinasi, namun pilihan ini tidak praktikal. Sementara itu, protokol laluan DTN yang sedia ada tidak membolehkan pemilihan persimpangan pertengahan yang sesuai untuk persekitaran yang jarang. Bagi mengatasi kelemahan ini, pendekatan baru telah diperkenalkan dalam kajian ini, yang

menganjurkan operasi penyiaran mesej beacon HELLO dalam VANEsT dengan mengambil parameter akaun tertentu. Setiap persimpangan dalam rangkaian menyiarkan mesej beacon HELLO berdasarkan kedudukan, vektor dan ramalan masa depan yang diperoleh daripada Arah Kenderaan Petunjuk Light (DIL). Maklumat DIL telah memperkenalkan buat kali pertama dalam domain kajian ini. Kedudukan yang berdasarkan protokol laluan DTN dicadangkan dalam rangkaian kenderaan untuk meningkatkan perhubungan di kawasan bandar. Penyelesaian ini direka untuk persekitaran yang sibuk yang mengalami kekerapan terputusnya rangkaian dengan mencadangkan pengantara mekanisma pemilihan persimpangan yang paling sesuai melalui proses pemilihan hop yang akan datang. Proses pemilihan ini menggunakan kedudukan persimpangan, arah semasa, kelajuan dan arah yang ramalan yang diperoleh daripada DIL. Prestasi cadangan protokol ini dinilai oleh NS-2 dari segi kecekapan, pengeluaran tambahan dan kelewatan hujung-ke-hujung berbanding dengan kerja sebelumnya. Simulasi eksperimen mengesahkan prestasi AGDR lebih unggul berbanding dengan skim kontemporari dari segi nisbah penghantaran paket, pengeluaran tambahan dan kelewatan hujung-ke-hujung. Keputusan simulasi menunjukkan bahawa AGDR meningkatkan nisbah penghantaran paket (5-7%), mengurangkan pengeluaran tambahan (1-5%) dan mengurangkan kelewatan (0.03-0.05 ms). Oleh itu, AGDR meningkatkan kestabilan laluan dengan pengurangan kekerapan kegagalan laluan.

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LIST OF ABBREVIATIONS

AGDR	Adaptive Geographic DTN Routing
AODV	Ad-hoc on Demand Distance Vector Routing
AU	Application Units
CALM	Communication Air and Long distance Medium
CAR	Connectivity-Aware Routing
CCH	Control Channel
CEDAR	Core Extraction Distributed Ad hoc Routing
CTD	Confirmation Time Duration
DIL	Direction Indicator Light
DSDV	Dynamic destination-Sequenced Distance-Vector Routing
DSR	Dynamic Source Routing Protocol
DSRC	Dedicated Short Range Communications
DTN	Delay Tolerant Network
ETC	Electronic Toll Collection
FCC	Federal Communication Commission
FSR	Fisheye State Routing
GeoOpps	Geographic Opportunistic
GloMoSim	Global Mobile Information System Simulator
GPCR	Geographic Routing in City Scenarios
GPS	Global Position System
GPSR	Greedy Perimeter Stateless Routing
GSR	Geographic Source Routing
IARP	Intra-zone Routing Protocol
IERP	Inter-zone Routing

InVC	In-Vehicle Communication
ITS	Intelligent Transport System
IVC	Inter Vehicle Communication
LORA-CBF	Location Routing Algorithm with Cluster-Based Flooding
MAC	Medium Access Control
MANET	Mobile Adhoc Network
MDDV	Mobility-centric Data Dissemination in Vehicular networks
MOVE	Motion Vector Routing Algorithm
NAM	Network Animator
NS-2	Network Simulator
NS-2	Network Simulator-2
OBD	On Board Diagnostics
OBUs	On Board Units
OLSR	Optimized Link State Routing Protocol
P2P	peer-to-peer
QoS	Quality of Service
ROVER	Robust Vehicular Routing
RREP	Route Reply
RREQ	Route Request
RSUs	Road Side Units
SADV	Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks
SCH	Service Channels
SUMO	Simulation of Urban Mobility
TCP	Transmission Control Protocol
U.S. DOT	U.S. Department of Transportation

V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VADD,	Vehicle Assisted Data Delivery
VANETs	Vehicular Adhoc Networks
VDTN	Vehicular DTN
WAVE	Wireless Access in Vehicular Environment
ZRP	Zone Routing Protocol

CHAPTER 1: INTRODUCTION

1.1 Introduction

Vehicular Adhoc Networks (VANETs) are expected to be incredible benefits for safety applications, gathering and disseminating real time traffic congestion and routing information, sharing of wireless channel for mobile applications etc. The interest for more trustworthy, predictable, secure and safer vehicular networks standard are steadily expanding because of emerging commercial applications such as Intelligent Transport System (ITS) and infotainment. The main goal of VANETs is to provide the drivers and passengers a safe and comfortable journey by minimizing the risks of accident. The most important characteristic of VANETs is the high mobility of the nodes. It is the fundamental cause of a series of VANET specific attributes requiring the expansion of applicable solutions. Therefore, such aspects are significant to consider when designing a data transfer scheme in VANETs. In urban areas the traffic density is high during rush hours, whereas roads experience lowers density in early morning, noon and late night. Hence routing algorithms for VANETs should be adaptive to allow multiple communications on different application. The performance and Quality of Service (QoS) of VANETs are depending on how the routing protocol is performed in the network. In general, routing is a process of forwarding data from a source to a destination which require multi-hop forwarding nodes. Specifically, routing protocols are responsible to determine the path to forward the packets to their destinations, and also to find alternative paths in case of failure. An efficient routing protocol is able to deliver a maximum number of packets in a short amount of time and consume minimal bandwidth. To obtain a high performance in various applications such as safety applications, rescue operation and infotainment, efficient and dynamic routing for VANETs are required. The main obstacle is to establish steady and reliable communication network, so for establishing such network, routing protocol design is one of the major challenges. An efficient routing technique in VANETs, specifically in sparse environment impacts on enhancing communication performance of data transmission to the target destination, reduce the packet overhead and maximize the data delivery in a minimum time. The unique characteristics of VANETs such as high mobility and constrained roads pattern generated a partially connected network. The prime concern is to discover and maintain a reliable communication path for the vehicular network which requires to maintaining up-to-date information about neighbour nodes which can be acquired either through continuous flooding of control packets or transmission of beacon messages. Sparse node density and frequent high speed mobility results in network partitioning and intermittent connectivity which makes it difficult for the packets to be delivered from source to the destination. In such dynamic environments, adaptive routing protocols are necessary that can discover an appropriate next-hop forwarder node (neighbour) on the path towards the destination. This selection should be made in such a way that improves data delivery probability with reduced delay and balances the network overhead.

The aim of this research comprises two main contributions. First, to introduce an adaptive HELLO beaconing procedure which is adaptively and effectively find the neighbour nodes using the real time information such as current position, direction, speed and predicated future direction with the aid of the equipped devices, such as Global Position System (GPS), Direction Indicator Light (DIL) and navigation system. AGDR are well adapted to continuously changing topology. It reacts based on the real time vehicle parameter as well as road parameter. It broadcast HELLO beacon message adaptively rather than periodically. i.e. when need to discover neighbour. This method efficiently reduces the overloading problem. Secondly, novel routing protocols for a sparse environment in VANET by utilising the mobility feature is developed. The selection of intermediate node is based on vehicle position, speed and direction (vector information) and predicted future direction which is generated from vehicle DIL. The adaptive delay tolerant routing operates in two modes; the first mode was developed for the intersection and the second mode was developed for freeway environment. The performance of the developed delay tolerant routing has been examine and analysis by simulation tools. The main goal of the proposed routing protocol is to minimize the reaction to mobility by maximizing the route stability and packet delivery. The developed protocol form and maintain a long lived route from source to destination and reduce the rate of link breakage in sparse VANETs.

1.2 Motivation

VANETs have significant potential to host diverse applications associated with traffic safety, traffic efficiency and infotainment. For such realization to happen, applications on VANETs are depending on routing protocols; realistic coverage of network on the road among vehicles as well as cooperation from drivers. In VANETs, routing protocols that exhibit a distinctive characteristic of networking environment is a subject of interest. Routing data packet in VANETs is a challenging subject and requires an extensive research. This because routing is the most vital scheme that applications rely upon. For successful implementation of VANET in any applications, its required an adaptation of appropriate routing protocol (Noureddine, 2011). The main motivation is to design and develop a new adaptive geographic delay tolerant routing protocol, with aim to increase the routing deliverability in vehicular networks. The protocol is expected to adapt in the topology variation of the vehicular node and responds to the nodes' movement. Ultimately, the high deliverability of the new protocol should be achieved with a low routing overhead, while maintaining a tolerable level of network delay. The motivations for the adaptive VDTN routing are listed as follows:

i) In a vehicular network, all the applications consider the node always available for transferring messages but its not realistic for highway and urban environment.

ii) The safety application is the most focused in VANET so, the efficiency and reliable communication has a vital impact on their contribution to limit the number of fatalities and provide safer, cleaner and more comfortable travelling experience on the roads.

iii) The main challenge in sparsely connected VANET routing is to find an appropriate intermediate node for transmitting the data packet to its final destination.

iv) Traditional routing protocols are not applicable to operate directly on delay tolerant networks as they are challenged with high latency, frequent disconnections, high error probability, and limited node longevity.

1.3 Statement of Problem

In the geographic routing algorithm, every node of the participating network knows its own and neighbour node's geographic position. Therefore, there is no need to maintain any routing table or exchange link state information with its neighbourhood node in such routing schemes. The nodes find this location information through the GPS. Though geographic routing is a potential way to forward data from source to destination in VANET, it also has some limitations. Delay Tolerant Network (DTN) routing protocols are still unable to satisfy the throughput and delay requirements. The problem of data delivery in VANET for a DTN is how efficiently the packet routes to the destination, and receive the reply within reasonable delay. It is needed to such a communication network in VANETs in which the vehicle communicate with other vehicles is very quickly and efficiently, for providing fast and reliable dissemination of messages, an adaptive data routing protocol is proposed in vehicular networks for the urban scenario. Though Vehicle Assisted Data Delivery (VADD) performs well in highway scenario but not suited for the urban area where lot of intersection and frequent network disconnection. VADD will aware about delay and data delivery in large-scale and dynamic VANETs under low vehicle densities but experiences dramatic performance degradation in the packet-delivery delays (Paul, Ibrahim, Bikas, & Naser, 2012). Mobility-centric Data Dissemination in Vehicular networks (MDDV) renders poor reliability and performance(Ahmed, Ali, & Hashem, 2013). Our research domain DTN in VANET is a subclass of geographic routing where handle the issue of low density vehicular networks. The essential purpose of the DTN routing protocol is to find out a reasonable data packet route from the source node to destination. The major problem is to maintain a constant and reliable communication for the DTN. Hence, routing protocol design for DTN is one of the major challenges. To maintain latest neighbour node information in DTN is one of another key challenge. This neighbour discovery is accomplished either by flooding the control packet or broadcasting HELLO beacon message (Ding & Xiao, 2010); which is a main concern of this thesis. The low density of nodes in VANETs produce disconnectivity of node in the network and negative effect on the performance as result, preventing the message transmission to their destination (Taleb et al., 2007). The challenge for routing protocol is the existence of network partitions due to minimal relative speed differences between vehicles (Christian Lochert, Mauve, Füßler, & Hartenstein, 2005). The vehicle may experience periodic connectivity from vehicles on the opposite lane in a two lane scenario(Casteigts, Nayak, & Stojmenovic, 2011). Hence the performance of routing protocol is very vital to increase message propagation and maintain higher degree of connectivity while network partitions occurs(Paul, et al., 2012). So an efficient adaptive delay tolerant routing make positive impact on network performance in terms of message transmission, minimize control packets overhead in a shortest delay. To overcome the problem of frequent disconnection in partition network a novel routing protocol is need to propose. Hence the research issue is to overcome the following issues:

i) Existing DTN routing such as Geographic Opportunistic (GeoOpps), Greedy Perimeter Stateless Routing (GPSR) not accurate in discovering the potential neighbours for the packet transmission.

ii) Excessive beacon message generated by the present DTN routing protocols contributed to the packet overhead problem.

iii) The current DTN routing protocols are unable to find the appropriate intermediate node in the sparse vehicular environment.

1.4 Objectives

The main objective of this research is to develop an adaptive geographic delay tolerant routing (AGDR) protocol in VANETs to increase the system's connectivity and route stability for the sparse environments.

The sub-objectives to develop an adaptive delay tolerant routing in VANETs are listed below:

i) To review recent advancement in VANET routing and identify the limitation of existing vehicular delay tolerant routing protocols

ii) To design a framework in adaptive VDTN routing protocol for discovering the potential neighbours.

iii) To develop an adaptive HELLO beacon procedure for neighbor detection in vehicular delay tolerant networks for overcoming the overhead problem.

iv) To develop a next-hop selection process for selecting the best intermediate node

v) To analyze the developed adaptive VDTN routing “Adaptive Geographic DTN Routing (AGDR)” protocol by efficiency, packet overhead and end to end delay.

1.5 Significance of Research

This research is expected to improve the message reception and reduce the delivery time of warning and control information. Such improvement will open doors to many applications in several domains that include safety, route planning, and emergency vehicle collision avoidance. These all can be based on simple driving events called mobility primitives. It also allow vehicle to obtain and disseminate the information about accidents, traffic jam, and road surface conditions that coming from other vehicles. Furthermore, the proposed routing algorithm is responsible for disseminating warning messages quickly and efficiently through the network for urban environments. The significance of the adaptive delay tolerant routing in VANETs is listed below:

i) This research will redirect the existing efforts in network connectivity in VDTN routing towards a prediction based on DIL information. It accurately selects the intermediate node for data transmission in sparse vehicular environment.

ii) Improves the efficiency and performance of beaconing for vehicular geographic routing. In this research, an adaptive beaconing is developed using the real time vehicle's and road parameter such as vehicle position, current direction, DIL information and speed.

iii) The framework for adaptive DTN routing and the next-hop selection process maintain a stable, robust network connectivity the consume minimal bandwidth and reduce packet dropping in partially connected vehicular network to increase road safety.

1.6 Thesis Layout

This thesis is organized as follows. Chapter 2 describes the fundamental knowledge of VANETs and its basic requirements. Also, the models for the wireless channel and medium access are presented. Then, the related works of VANET routing protocols, taxonomy and the importance of delay tolerant network are reviewed in Chapter 3. In Chapter 4, research methodology and proposed framework for adaptive delay tolerant network are explained. This followed by describing the proposed routing protocol targeted at VANET in DTN for urban network. Chapter 6 discusses the simulation setup and results for the proposed routing protocol. Finally, the conclusion and future work are outlined in Chapter 7.

CHAPTER 2: VANET TECHNOLOGY

2.1 Introduction

With the continuous development of wireless communication technologies, vehicles are now becoming computers on wheels by being equipped with intelligent electronic devices called On Board Units (OBUs). Each OBU includes a computer processor, a GPS, sensing devices, storage devices and a wireless transceiver, providing ad hoc network connectivity for the vehicles. Equipped with OBUs, vehicles can now communicate with other vehicles while moving on the roads or with fixed roadside infrastructures when passing by them (Sichitiu & Kihl, 2008). These communication methods are referred to as Vehicle-to-Vehicle (V2V) communication and Vehicle-to-Infrastructure (V2I) communication and basically form the VANETs. The fixed roadside infrastructures or Road Side Units (RSUs), are futuristic dedicated infrastructure elements, similar to base stations of mobile telecommunication system (Corazza et al., 2012). These RSUs would most likely be located at critical points of the road, such as intersections or construction sites, and are intended for providing message dissemination, security and network stability for vehicular networks. For this purpose, 75 MHz of spectrum in the 5.9 GHz band has been allocated in North America for the Dedicated Short Range Communications (DSRC) standard, a set of communication protocols and standards specifically designed for vehicular communications (Kenney, 2011). This channel is a means through which real time multimedia applications, including Peer-to-Peer (P2P) content provisioning, can be deployed in the future and various services can be provided. A similar band has been allocated in Europe and Japan. VANET is a kind of ad hoc network, but significantly differ from other wireless ad hoc networks, such as sensor networks, mobile ad hoc networks, etc. The communication links in such networks have short connection times due to the high mobility of vehicles. VANET's aim is even to avoid accidents using periodic broadcast of messages containing vehicles' status information such as position and vector information and a safety system aware of its surrounding to detect potential dangerous situations for the driver.

In this chapter we are going to describe about different technology of VANETs. After defining the vehicular network, identify the characters of VANETs. Different types of application of VANETs explain in section 2.4. Make an explanation of vehicular communication type and finally challenges of VANETs technology are discussed.

2.2 Vehicular Adhoc Networks

Vehicular adhoc network is a form of MANET that provides communications between vehicles and nearby fixed equipment, usually described as roadside equipment (Boukerche, Oliveira, Nakamura, & Loureiro, 2008). Vehicular networks will contribute to safer and more efficient roads by providing timely information to drivers and concerned authorities (Jerbi, Senouci, Rasheed, & Ghamri-Doudane, 2007). In VANETs, vehicles tend to move in an organized fashion. The interactions with roadside equipment can likewise be characterized fairly accurately. Most vehicles are restricted in their range of motion, for example by being constrained to follow a paved highway. A VANET tends to operate without any infrastructure or legacy client and server communication. Each vehicle equipped with VANET device will be a node in the ad-hoc network and can receive and relay others messages through the wireless network. Collision warning, road sign alarms and in-place traffic view will give the driver essential tools to decide the best path along the way. To this end a special electronic device will be placed inside each vehicle which will provide ad-hoc network connectivity for the passengers.

A typical vehicular network is represented in the following figure 2.1.

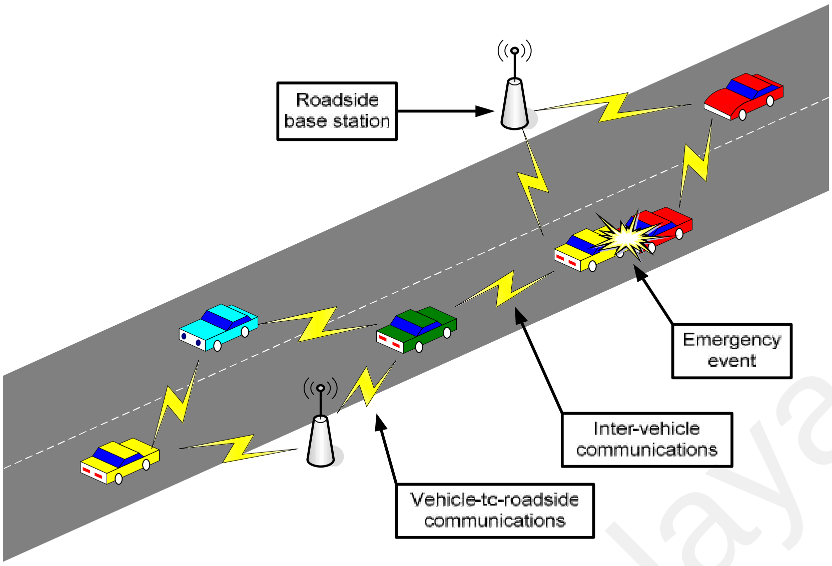

Figure 2.1: A typical vehicular network

2.3 VANET Characteristics

VANETs have distinct characteristics in several aspects than traditional fixed network and MANETs. The differences are immense that most of the current routing protocols and communication models for the MANET cannot be applied for the VANETs (Sharef, Alsaqour, & Ismail, 2014). In VANETs, the mobility of the node is very high as the relative velocities of the node up to 200km/h in highways make the distinct in characteristics. This high mobility make the network topology change very frequently and exist for very short time (Christian Lochert, Mauve, Füßler, et al., 2005). However by using the digital roadmap and some other fact the common vehicle move on roads topology change and mobility pattern something predictable (Sichitiu & Kihl, 2008). For example, in highway scenario the typical link time of two communicating nodes of opposite direction is approximately less than 5s if the transmission range 160m. Whereas if the node in the same direction, the link time is greater than 50s. VANETs transmit information with or without any infrastructure, is a characteristics of ad hoc network the high mobility environment leads to a rapid time variant radio propagation channel (Galaviz-Mosqueda, Villarreal-Reyes, Galeana-Zapién, Rubio-

Loyola, & Covarrubias-Rosales, 2014). Hence appropriate physical and MAC layer are needed which can perform data transmission with adequate reliability. Vehicle density have importance for vehicular ad hoc communication, since it has great consequence with network connectivity (Agarwal & Little). A higher density means more chance of connectivity and more possible applications for the user whereas low density creates sparsely connected or partitioned VANETs so that in most cases there is no node for the communication in the transmission range. The deployed technologies should be adjusted or configured with the different changing environment from high density to low density. The relation of information is also a very important characteristic for VANETs. Most application in vehicular network is aim to transmit information of the neighbour node which has been discovered by neighbour vehicle in the transmission range. As the specific destination addresses of the prospective communication node are unknown and irrelevant, the broadcast method is applied. However, a broadcast technique generate excessive control message which occupy the major part of bandwidth (Wisitpongphan et al., 2007). A different technique can be used for the comfort application is to use of the high level of redundancy in vehicular network. An incident is normally discovered by numerous vehicles; consequently a vehicle can identify a possibly specious message by comparing it with information acknowledged from neighbouring vehicles. Computational power, memory and energy are not as restricted as in a MANET or sensor network and allow more complex data dissemination protocols (Luo & Hubaux, 2004). It is vital to realize the key features of VANET in order to develop efficient, robust and dynamic information propagation schemes. The characterization of VANET can be conceded out either by simulation studies or real-life test-bed. Simulation studies provide us the understanding to perceive the effect of topology changes and network partitions in large scale networks. Experimental studies on VANET are typically smaller in scale and usually fail to show the effect of inclusive topology variations. Whereas real experiments demonstrated the effect of interference caused by many factors, which is usually difficult to simulate. The most important characteristics of VANETs are discussed below:

i) Roadside Infrastructure: The use of fixed roadside communication infrastructure (e.g., fixed access points) is distinctive to VANETs. The fixed RSU with storage can maximize the capability of the network. In literature, there are numerous routing protocols which utilize the fixed RSU access points in order to increase the data delivery ratio. These fixed infrastructure are also accountable for upgrading links that are damaged due to mobility (Yousefi, Mousavi, & Fathy, 2006).

ii) Vehicle Density: Traffic congestion and network partitions are very common in VANETs distribution of vehicle in road is random. The high mobility and frequent network fragmentation is usual a phenomena in VANETs. Normally, the connectivity increases with density of vehicle but after a critical value the connectivity falls down against the increase of vehicle density. The message transmission is delayed after the density of vehicle is increased to greater than the critical value.

iii) Transmission Range and Time: In general, connectivity is lost abruptly outside the radio propagation range. At least 500 meters of radio range are essential to stay well connected. A node can only reach 37% of the other nodes if the transmission range is 500 meters. The radio propagation range and driving direction are directly affected by connection lifetime. From the simulation result it was found that 90% of all paths have less than 50 seconds of connection life time (Wang, 2004). An increase in path length decreases the connectivity.

iv) Environmental Factors: Vehicles can travel into many different environments such as highway environments, urban environment, disaster situation, extreme weather conditions etc. which can restrict the wireless communications. In urban environments, many tall buildings may impede and restrict with the radio propagation signals. A common phenomenon in built-up environment is the multi-path fading. Vehicles commonly remain closer together than in highway scenario; therefore may produce interference if radio transmission range is increased by increasing the power of radio communication equipment.

v) Mobility: Mobility that is the norm for vehicular networks makes the topology change quickly. Besides that, the mobility patterns of vehicles on the same road will exhibit strong correlations. The mobility of vehicles is highly foreseen because there are only two moving directions for the vehicles on the same road.

vi) Connectivity: The management and control of network connections among vehicles and between vehicles and network infrastructures is the most important issue of VANETs communication. Primary challenge in designing vehicular communication is to provide good delay performance under the constraints of vehicular speeds, high dynamic topology, and channel bandwidths.

vii) Power Management: All communication devices have plenty of electric power provided by vehicles.

viii) Security: Security in VANETs is of special concern because human lives are constantly at stake whereas in traditional networks the major security concerns include confidentiality, integrity and availability none of which involves primarily with life safety. Security in VANET indicates the ability to determine the driver responsibility while maintaining driver privacy. Information about the vehicles and their drivers within must be exchanged securely and more importantly, timely in that the delay of message exchange may cause catastrophic consequences such as collision of vehicles.

2.4 Applications of VANET

VANET communication provides a numerous of application in present computing environment. Moreover the focus of this thesis is on increasing the efficiency of safety applications, which can be improved by developing a new routing protocol that support this type of application. Applications in VANET are mainly classified in two classes as:

2.4.1 Safety Application

Safety applications typically demand a direct message exchange from vehicle to vehicle due to the inflexible delay requirements. This application has a stronger requirement for reliability and integrity of communication compared to comfort application. As VANETs are based on Inter Vehicle Communication (IVC), the possible communication depends on the number of vehicular nodes equipped with an IVC system. Safety applications are normally assumed that at least one vehicle involved in the critical situation will broadcasts an emergency notification in the VANETs. Due to their stringent requirements on consistency and delay, safety applications uniquely based on IVC will not be feasible until a relatively large fraction of vehicles is equipped with an IVC system (Wischhof, 2007). A different channel is used for the safety applications than comfort applications and the problem of the hidden terminal and the exposed terminal is deal by the MACs since they may be devastating for the safety application. Two types of safety messages are found in the safety application; event driven messages and broadcast messages. Broadcast messages are sent for the purpose of detecting non-safe situations like as transmit information (e.g. position, speed, direction etc.) about the neighbour vehicles. The event-driven messages are generated on demand, such as an alert in a dangerous situation or a request in routing protocol. Rapid dissemination of the message is very important to avoid an accident in the event-driven type. Normally the safety application are categorized as commence applications in which the major purpose is to broadcast certain event that have occurred in the neighbourhood of the sender. Example of the safety applications are:

i) Signal violation warning
ii) Rescue Operation
iii) Collision risk warning
iv) Hazardous location notification and Control Loss Warning
v) Cooperative collision avoidance (Biswas, Tatchikou, & Dion, 2006)
vi) Lane-changing assistant, intersection coordination(Xu, Mak, Ko, & Sengupta, 2004)
vii) Driver assistance systems, e.g. for overtaking, lane merging
viii) Traffic information for dynamic route updates, depending on existing obstructions of traffic
ix) Weather information (temperature and road condition
x) Enhanced Adaptive Cruise Control (ACC) systems which augment the information of the on-board (radar or LIDAR) sensors with information received via the VANET.

2.4.2 Comfort and Convenience Application

The aim of comfort and convenience applications is to offer convenience and comfort to drivers and/or passengers. Comfort applications improve passenger comfort and traffic efficiency. Comfort and convenience application mainly deals with traffic management with a goal to enhance traffic efficiency by boosting the degree of convenience for drivers. Comfort application continuously updated traffic or weather information generate significant amounts of data traffic, while large number of users are not willing to expend much for these kinds of services. Hence, the major improvement of VANETs compared to infrastructure based communication for applications in this category is the prevention of service charges for communication since no service provider is required. Examples of comfort and convenience are:

Typical convenience and personalized applications are:

i) Speed management and Co-operative navigation
ii) Internet Protocol TV (IP-TV)
iii) Global Internet services
iv) Co-operative local services
v) Entertainment services such as gaming, chatting and music download
vi) Roadside advertising/marketing
vii) Services providing travel information such as gas station, tourist or restaurant information,

2.5 Types of Vehicular Communications

The latest developments in vehicular network technology enable the vehicles to communicate with each other with or without fixed infrastructures. The increasing availability and accuracy of communication systems has reinforced the need for a dynamic communication technology. Different equipment continually exchanges the available information and assists to ensure driver safety and comfort. Moreover, the vehicle can communicate with the other vehicle by wireless communication. The technologies for vehicular communication can be categorised according to their functional behaviour and characteristics as follows:

i) Vehicle-to-Vehicle (V2V) communication
ii) Vehicle-to-Infrastructure (V2I) communication

The following section gives a brief description of the state-of-the-art vehicular communication and existing standards.

2.5.1 Vehicle to Vehicle (V2V) Communication

V2V communications for safety is the wireless exchange of data among vehicles travelling in the same vicinity that offers opportunities for significant safety improvements. V2V communication contributes to the exchange of information between OBU and Application Units (AU). V2V communications for safety is a key component of the connected vehicle research program within Intelligent Transportation Systems Joint Program Office (ITSJPO) of the U.S. Department of Transportation (USDOT) Research and Innovative Technology Administration (RITA). Through the multimodal program, the ITSJPO and the private sector are able to share information between vehicles to achieve transformative safety benefits for the multimodal transportation sector.

The following figure 2.2 shows the V2V system.

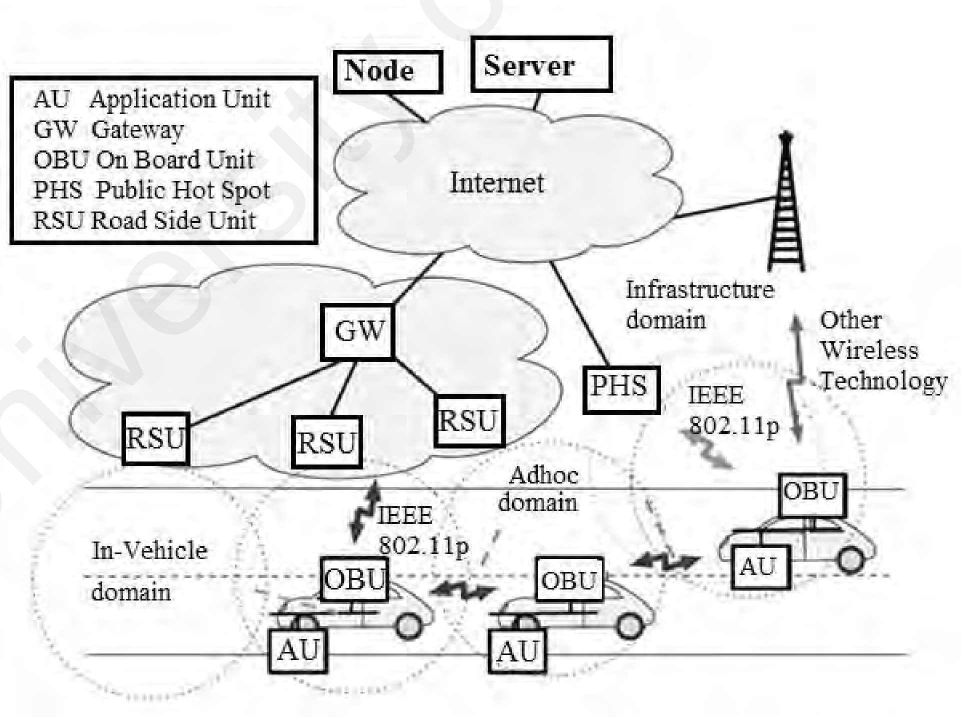

Figure 2.2: Vehicle-to-Vehicle Communication

2.5.2 Vehicle-to-Infrastructure (V2I) Communication

V2I communications technology for the wireless exchange of vehicular network is used for the critical safety and operational environment to enable a wide range of distinct safety, strength and environmental benefits. V2I conveyance applies to all vehicle types and roads, transforming substructure equipment into “smart infrastructure” through the incorporation of routing protocol that use data exchanged between vehicles and infrastructure. The equipments of V2I perform calculations that recognize high-risk situations in advance, resulting in driver alertness and warnings through specific counterbalance. The important advancement is the ability for traffic signal systems to communicate the signal phase and timing information to the vehicle. That’s supports support to the driver in delivering active safety advisories and warning messages. The V2I communications is reduced crashes that can help to accelerate the deployment of V2I technology. The V2I communication program is designed to enable the exchange of data over a wireless network which enables each vehicle on-board equipment, device or roadside equipment to perform calculations and issue driver advisories and warnings to avoid or mitigate crashes through specific advanced safety applications. It will conduct the activities that will formalize, rating and evaluate benefits for high value applications and enable national interoperability for the transmission of safety related information exchange between roadside equipment and/or nearby vehicles.

2.6 VANETs Protocol Stack

This section discusses the VANETs protocol stacks in detail. The discussion focuses on Network, MAC and PHY layers for WAVE and CALM.

2.6.1 Wireless Access for Vehicular Environments

Dedicated Short Range Communications (DSRC) is allocated by the U.S. Federal Communication Commission (FCC) a 75MHz wide spectrum band at 5.9GHz for exclusive V2V and V2I communications. In Europe, a similar band was recently allocated for the same purposes. The DSRC spectrum is mainly proposed to maintain public safety applications that decrease the harshness of vehicle accidents, save lives, and advance the traffic service. The availability of effective localized communications support timely information sharing among vehicles and infrastructure. The U.S. FCC allows for non-safety DSRC applications to support development and deployment of DSRC technologies. The U.S. DSRC spectrum is made up of seven 10MHz wide channels, as shown in Figure 2.3. Channel 178 is use as control channel (CCH). CCH is the default channel for common safety communications. The two channels are reserved at the ends of the spectrum band for special uses. The rest are service channels (SCH) available regularly for safety and non-safety use. Broadcasting of advertisement messages over the CCH to deliver information on which services are currently available in service channels.

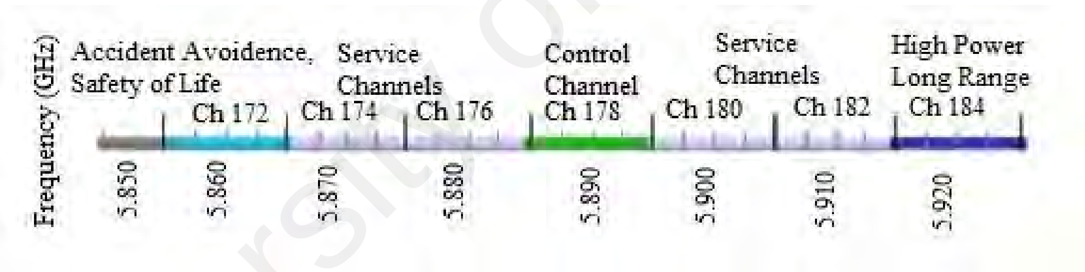

Figure 2.3: DSRC channels spectrum

Wireless Access for Vehicular Environments (WAVE) is an approved amendment to the IEEE 802.11 standard and also known as IEEE 802.11p. WAVE is required to support the Intelligent Transportation Systems (ITS) applications in the short-range communications. The data transmission among vehicles (V2V) or between the vehicles and the roadside infrastructure (V2I) is relied on the band of 5.9 GHz. DSRC is the wireless communication protocol for the vehicles. WAVE is the core of the DSRC; ensures the traffic information collection and transmission immediate and stable, and keeps the information security. Figure 2.4 compares WAVE protocol stack to the

Transmission Control Protocol (TCP) stack, WAVE stacks model have the same physical and data link layers, but it differs in the network and transport layers. Security layer does not fit in the TCP protocol stack. In general, IEEE 802.11p and IEEE 1609.4 are used to describe the physical and the Media Access Control (MAC) layer of the system respectively. While IEEE 1609.3, with its two supported stacks (e.g. Internet Protocol version 6 (IPv6) stack and WAVE Short Message Protocol (WSMP) stack) is used to describe a network layer and transport layer of the TCP stack. Security functions and services are described by an IEEE 1609.2 standard protocol.

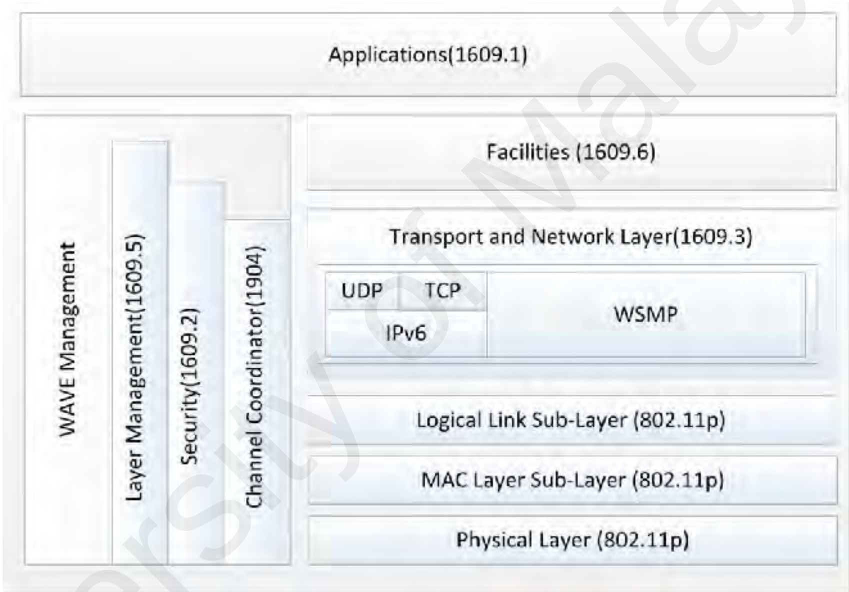

Figure 2.4: WAVE

2.6.2 Communication Air and Long distance Medium

ISO CALM was developed to provide continuous V2V and V2I communication. The CALM is based on heterogonous cooperative transmission framework from various project such COOPERS and SAFESPOT included the main idea of CALM in their work. The CALM standard is also mainly based on 5.9GHz DSRC concept. CALM recommends Infrared for short and medium distances, similarly, for long distance it prefers the use of GSM, UMTS or any other technology available at PHY layer (Mohammad, Rasheed, & Qayyum, 2011). A management entity (CCME) is well-defined in CALM to offer adaptability, elasticity and flexibility features. Fundamentally CCME comprise of three components which are as follows:

i) CALM Interface Manager: Each communication interfaces are monitor by CALM interface manager and store the status of each communication, along with its channel quality which supports in taking decisions.

ii) CALM Network Manager: CALM Network Manager responsible for the process of handover to alternate media.

iii) CALM/ Application Manager: CALM application manager guarantee the communication requirements. It interacts with interfaces to receive data about the most appropriate medium and instructs the CALM network manager to establish the connection. Figure 2.5 depicts the intra and inters layer entities and their interaction in CALM.

ISO CALM is actually very flexible in developed, with less than 1ms link setup time. It is popular in its design as it provides a combination of different technologies for communication as well as it has a space in its design to incorporate future technologies. As CALM is a combination of different technologies so its operation and specification of diverse interfaces is hard job.

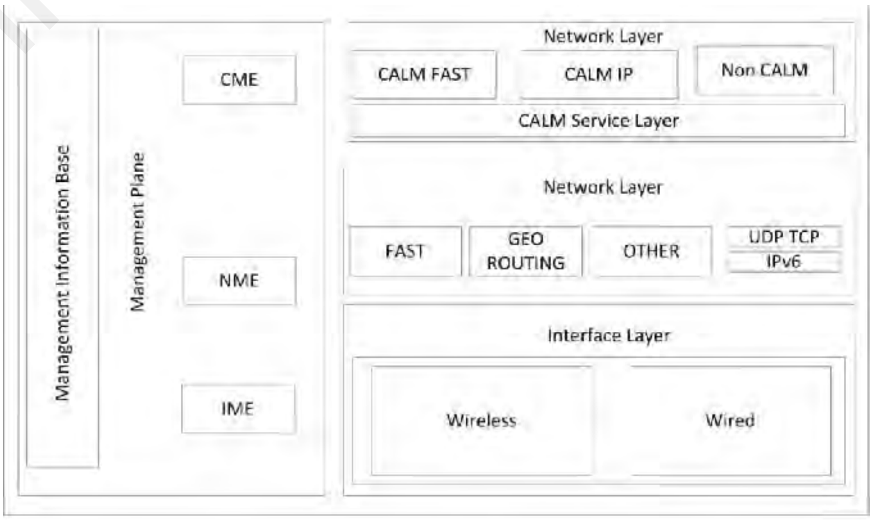

Figure 2.5: CALM

2.7 Challenges and Requirements in VANET

The non-interoperable vehicular network technologies have emerged with the rapid development and availability of mobile computing systems and environments. In VANETs, some future perspectives should be considered to design new efficient communication approaches. In urban scenarios, the VANET topology can have hundreds of vehicles in peak hours of a relatively small region. In this case, it is necessary to design protocols for medium access control to avoid collision and transmission errors. The issue of concern in this thesis is higher delay and lower reliability delivery, which are more constant in sparse networks. To increase the delivery reliability, several solutions make use of the carry-and-forward technique, which further increases the information delivery time. The term carry-and-forward referred as where a moving vehicle carries a data packet until it reach to the transmission range of a new vehicle, the node comes into its vicinity and forward the packet. In the urban environment off-peak hour experience lower density so the topology is sparser and the connectivity is more intermittent. This scenario suggests the need for protocols that are aware of these disconnections. Also, vehicles that travel in the scenario need to adapt their behaviour to network density variations in order to provide good data transfer. Network fragmentation is a challenge for network designers since it causes some of the nodes to become unreachable. Network fragmentation may occur in scenarios of light traffic areas. To realise the requirements needed to deploy VANET concept, many factors that have a significant impact on achieving the VANETs goal need to be taken into consideration, represented by non-safety applications and safety applications. Therefore it is very important to specify the main important challenges in VANET, and the key challenges from the technical perspectives are mobility, signal fading, bandwidth limitation, security and privacy, connectivity and rapid change of topology.

2.8 Conclusion

In this chapter the detailed description about VANET technology was presented. The goal of VANETs is to provide communications between nearby vehicles and nearby fixed equipment, usually described as roadside equipment, to support applications that improve overall security in road traffic. Vehicular networks will contribute to safer and more efficient roads by providing timely information to drivers and concerned authorities. The interesting research area of vehicular networks is where ad hoc networks can be brought to their full potential. The purpose of VANET is to provide ubiquitous connectivity while on the road to mobile users, who are otherwise connected to the outside world through other networks at home or at the work place, and efficient V2V communications that enable the ITS. V2I networks have fixed infrastructure and instead rely on the nodes themselves to provide network functionality. However, due to mobility constraints, driver behaviour, and high mobility, V2I networks exhibit characteristics that are dramatically different from many generic MANETs. V2I would perform crucial functions in collision avoidance, road-hazard notification, and coordinated driving systems. The performance and QoS of VANETs depend on how the routing protocol performs in the network. To establish a reliable communication network routing protocol design is the main challenges. The detail about routing protocol is discussed in the next chapter.

CHAPTER 3: ROUTING PROTOCOLS IN VANETS

3.1 Introduction

Vehicular Ad hoc Networks (VANETs) desire dependable routing protocols to protected and trusted communication environment. Routing protocols are exhibiting the distinctive characteristics of a networking environment. Routing algorithms for VANETs should be optimized and be dynamic to allow multiple communication on different application. The performance and quality of service (QoS) of VANETs depend on how the routing protocol performs in the network. In general, routing is a process of forwarding data from a source to a destination which require multi-hop forwarding nodes. The nodes in VANETs are themselves formed by vehicles with high mobility. Nodes in VANET join and leave the network frequently, which results frequent path disruptions. The time varying vehicle density results in a rapid change in topology, which makes preserving a route is difficult task. This in turn, results in low throughput and high routing overhead. The issue of temporary network fragmentation and the issue of broadcast storm further complicate the design of routing protocols in VANETs. The routing protocols in VANETs should be capable of establishing the routes dynamically and maintaining the routes during the communication process. They should be capable of discovering alternate routes quickly on-the-fly in the event of losing the path.

In this chapter investigate recently published articles about ad-hoc routing protocols for VANETs are investigate. Several routing protocols have been defined by many researchers. With the passage of time there is a need to have new protocols in order to have successful communication. The history of VANET routing begins with the traditional MANET routing protocols. Several topological based routing protocols for MANETs have been analyzed and adapted for VANETs. The main aim of our literature survey is to summarize all the VANET routing protocols and to analyze them comparatively then find the problems in our research domain geographic delay tolerant networks.

3.2 Classification of Routing Protocols in VANET

VANETs are highly dynamic topology due to frequent route disconnections occur as vehicles move. Vast numbers of protocols have been developed to cater for VANET specific routing requirements. Different researchers have classified these protocols in different categories; but here divide these routing protocols into five broad categories. We also describe the comparative analysis and find the merits and demerits of each subclass. The classifications of routing protocol are topology based routing, position based routing which is the alias of geographic routing, cluster based routing (Tao, Weiwei, Tiecheng, & Lianfeng, 2010), geocast routing and broadcast routing. Figure 3.1 shows the classification of VANET routing protocols.

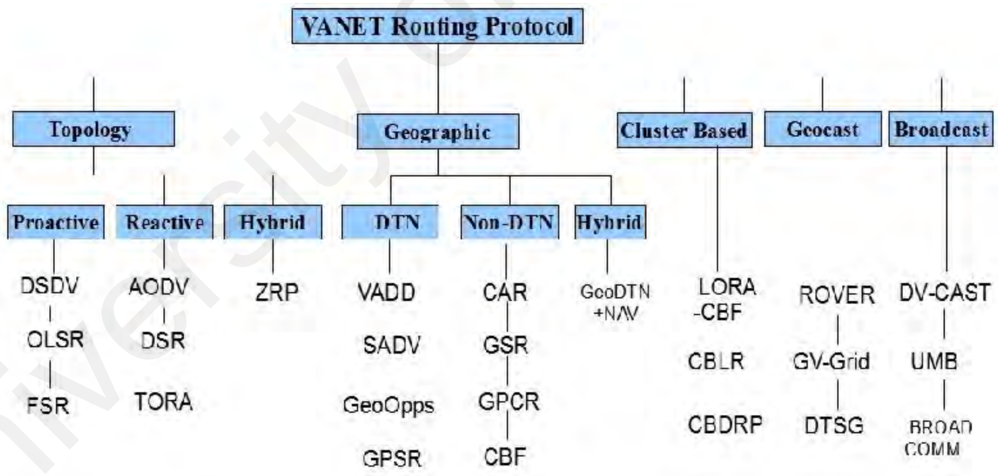

Figure 3.1: Classification of VANET routing protocol

3.3 Comparative Study

The detailed comparative study of the VANETs routing are described below.

3.3.1 Topology Based Routing Protocol

Topology-based routing protocols attempt to balance between being aware of all possible paths and keeping the overhead at a minimum level. These routing protocols employ routing data that occurs in the network to accomplish packet forwarding. Topology based routing protocols are divided into Proactive, Reactive and Hybrid Protocols.

3.3.1.1 Proactive Routing Protocol

This type of routing protocol is table driven and is similar to the connectionless protocol of conventional TCP/IP networks. Proactive protocols conserve routing information about the available paths however if the network routes are rarely used, such protocols need periodic updates in the routing table. Thereby a major part of the existing bandwidth is wasted and not appropriate for the high mobility network. The most important characteristic of proactive routing protocol is the absence of route discovery before communication between real time applications resulting in low route finding latency. The examples of this type of routing protocol are DSDV(Charles E. Perkins & Bhagwat, 1994), OLSR (Clausen & Jacquet, 2003) and FSR (Guangyu, Gerla, & Tsu-Wei, 2000). The proactive routing protocols are described below:

Destination Sequence Distance Vector Routing (DSDV)

DSDV is a kind of table driven protocol. DSDV provides loop free routing, minimizing the extra traffic by making frequent updates in routing table. It also minimizes the routing overhead and chooses the optimal path by using the shortest path algorithm. In order to avoid the duplication entry into the routing table DSDV assign sequence number. DSDV does not provide multi path routing and they do not have any control over network congestion (He, 2002). The availability of paths to all destinations in the network always shows that less delay is required in the path set up process.

Optimized Link State Routing Protocols (OLSR)

The OLSR is a table driven (proactive) protocol. As the name specifies, it uses the link-state scheme in an optimized way in order to disseminate topological information throughout the network. In OLSR, the protocol runs using the wireless multi-hop scheme; message flooding in OLSR is optimized to conserve available bandwidth. OLSR protocol is proactive protocol; so its operation primarily consists of updating and maintaining information in routing tables. The data in routing tables and other tables is based on received control traffic and control traffic. Thus it can clearly be understood that OLSR does not route traffic. OLSR is not responsible for the actual process of routing traffic in any way. OLSR could be considered as a route maintenance protocol in that it is responsible for maintaining the routing table used for route the packages (Clausen & Jacquet, 2003). OLSR makes use of "Hello" messages to find its one hop neighbours and its more than one hop neighbours through their responses. The sender can then choose its multipoint relays (MPR) based on the one hop node that offers the best routes to more than one hop nodes. Each node has also an MPR selector set that enumerates nodes which have selected it as an MPR node. OLSR uses topology control (TC) messages along with MPR forwarding to broadcast neighbour information over and done with the network. Host and network association (HNA) messages are used by OLSR to circulate network route advertisements in the same way TC messages advertise host routes.

Fisheye State Routing (FSR)

The FSR (Pei, Gerla, & Chen, 2000) formulates a mechanism for a node to store accurate route information about its immediate neighbours; and for the neighbours far apart, comparatively less route details are stored. FSR falls in the category of link state routing where information about the links is recorded and flooded. However, in FSR this information is only shared with immediate neighbours and is not flooded across the network. FSR performs relatively well when compared to Dynamic Source Routing Protocol (DSR) (David B. Johnson, 2001) and Temporally Ordered Routing Algorithm TORA (V. D. Park & M. S. Corson, 1997) but due to lack of information stored about distant neighbours the routing may become inaccurate as the distance from the node to destination increases as shown in figure 3.2. It also shares along with other topology based routing protocols the property of not scaling well to increasing network size. FSR is a topology based proactive routing protocol which is best suited for urban areas and does not require any virtual infrastructure. Delivery rate and control packet overhead is high in FSR. The links are established by considering path states and its applicability for a certain propagation model is unknown.

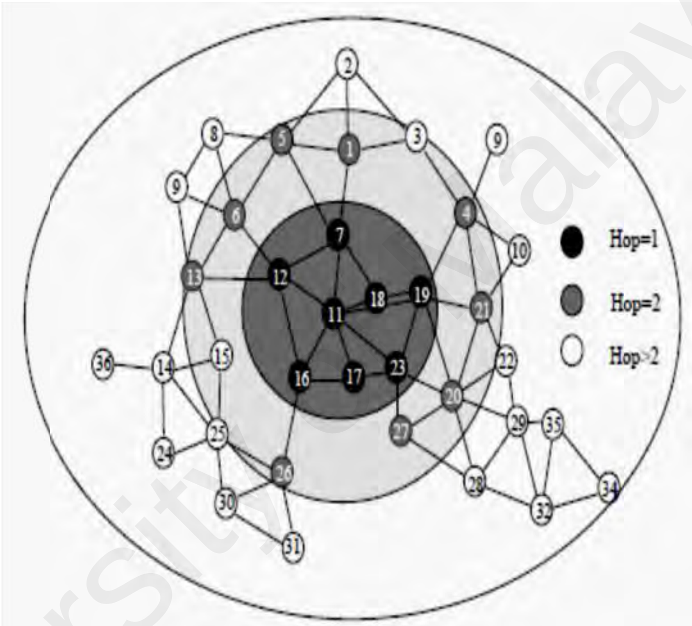

Figure 3.2: Fisheye State Routing Protocol

3.3.1.2 Reactive Routing Protocol

Reactive routing protocols do not maintain any prior routing table. In this type of protocols, a node discovers the route to destination whenever a packet needs to be sent. These protocols keep a routing table or build a routing table when a node request for a packet or a node needs to send a packet so that a route can be found effectively(Kang & Ko, 2010). This category of routing protocols is also known as on-demand routing protocols. Reactive protocols consume less bandwidth than proactive protocols; nevertheless the delay in determining a route can be substantially larger. A major disadvantage is that excessive flooding of the network which causes disruption to the communication of nodes (Bijan Paul, Md. Ibrahim, & Md. Abu Naser Bikas, 2011) and the packets transmitted to the destination are lost if the route to the destination changes. The examples of such type of routing protocols are Ad-hoc on Demand Distance Vector Routing (AODV) (C. E. Perkins & Royer, 1999) and DSR (David B. Johnson, 2001) , TORA (V. D. Park & M. S. Corson, 1997). Some highly cited protocols in this category are delineated bellow:

Ad-hoc on Demand Vector (AODV)

AODV (C. Perkins, Belding-Royer, & Das, 2003) finds a route from source to destination through a technique called backward learning. If destination is not a source node's neighbour then a broadcast RREQ message is generated. A node receiving RREQ will reply with a RREP containing the path to the destination or otherwise rebroadcast RREQ. Traversal of RREP ensures that every node maintains a forward path from source to destination. Sequence numbers are used as a mechanism for preventing loops and segregating between different RREQ messages. Due to its high packet overhead AODV suffers from low packet delivery rate in roads with a high density of vehicles. Being a protocol designed originally for MANETs, researchers have introduced several extensions to AODV to make it more scalable and robust for VANETs. Figure 3.3 shows a PREQ message broadcast to find a destination and the path of a destination message RREP. AODV performs well in urban areas without any virtual infrastructure. It has a high delivery rate and packet overhead in a dense network of nodes and it relates to probabilistic propagation model.

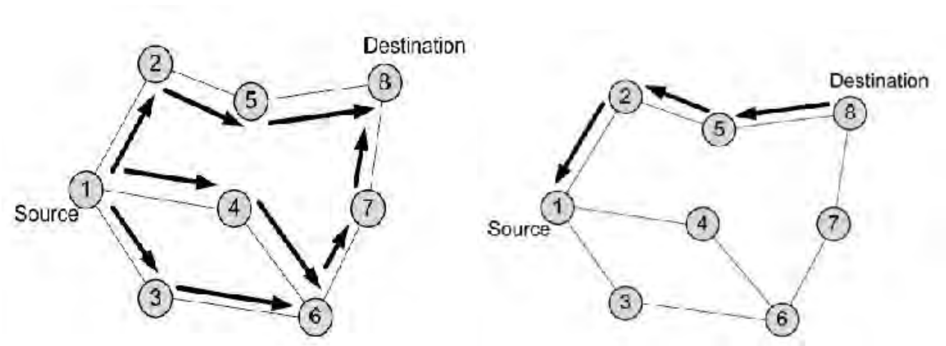

Figure 3.3: Propagation of PREQ and Path of the PREQ to the source

Dynamic Source Routing

The Dynamic Source Routing (DSR) mainly represents the source utilized in routing and active routes maintained in the network (Johnson, 2003). DSR has contained two processes like discover the route and maintain the routes. The route establish between nodes, during this process small overload on the network is generated. Then it will use caching process to reduce the load on the network for future discovery process. In DSR periodically updating not required. If the network has huge structure then the route information store in the header which leads to byte overloading. Unwanted flooding load the network. Inadequate to repair the broken links. Due to high mobility model it performs worse.

Temporally Ordered Routing Protocol (TORA)

Temporally Ordered Routing Protocol is establishing the link reversal algorithm that creates a direct acyclic graph like tree tend to the destination where the source node acts as the root of the tree. In TORA data packets are broadcasted at sending node and rebroadcasted done by neighbours at receiving node (V. Park & M. S. Corson, 1997). It follows the DAG, if the sending node at downward position and creates the DAG when needed. Overhead is reduced because all intermediate nodes no need to broadcast the message in the network. In dense network the performance is good. DSR and AODV perform well as compared to TORA so it is not used.

3.3.1.3 Hybrid Routing Protocol

Hybrid routing protocol is a combination of both proactive and reactive routing protocols. Such protocols are introduced with an objective to minimize the packet control overhead and route finding latency in proactive and reactive routing schemes respectively. The most typical hybrid routing protocols are Zone Routing Protocol (ZRP) (Zygmunt J Haas, Marc R Pearlman, & Prince Samar, 2002) and Core Extraction Distributed Ad hoc Routing (CEDAR) algorithm . The latter selects a minimum set of nodes as a core to perform QoS route computations. ZRP hybrid routing explains bellow:

Zone Routing Protocol (ZRP)

ZRP (Zygmunt J Haas, et al., 2002) tries to overcome the disadvantages related to route discovery latency and high packet overhead in reactive and proactive routing protocols respectively. This is achieved by implementing a proactive routing scheme within the transmission range (zone) of a node and reactive routing scheme for nodes that befall outside the zone of a node. Message passing within the zone is accomplished through Intra-zone Routing Protocol (IARP)(Zygmunt J. Haas, Marc R. Pearlman, & Prince Samar, 2001) which maintains route and metric information about neighbours of every node. If the node to be reached is outside the zone then the source sends a request message to the outer node of the zone. This message is broadcasted until a route to the destination is found. This part of routing is based on a reactive routing scheme i.e. Inter-zone Routing (IERP) (Zygmunt J. Haas, Marc R. Pearlman, & Prince Samar, 2002). Like reactive and proactive protocols, hybrid routing protocol can also perform in urban areas. It reduces the control overhead ensuring a higher delivery rate. It considers link states and shares the same probabilistic propagation model as of AODV.

3.3.2 Geographic Routing Protocol

In geographic routing algorithm every node of the participating network knows its own and neighbour node's geographic position. There is no need to maintain any routing table or exchange any link state information with its neighbourhood node in such routing schemes. The nodes find this location information through the GPS. Geographic routing protocols are more appropriate for VANETs since the vehicular nodes are known to move along established paths. The routing overhead is minimized in these types of protocols because no routing tables are used or created. The geographic routing protocols are of three types; Delay Tolerant Network (DTN), non-DTN and Hybrid.

3.3.2.1 Delay Tolerant Network (DTN)

DTN algorithms take some necessary steps to overcome intermittent connectivity in urban areas. The carry-and-forward strategy is used to cater for frequent disconnections of nodes in the network. In carry-and-forward strategy when a node cannot contact with other nodes it stores the packets and forwards them upon connection to a neighbouring node. The frequent disconnection problem in a DTN is one of the major challenge (Pereira et al., 2012). A delay tolerant routing in VANETs is smart solution for a partially connected network in off peak hour of the urban environment and in rural highways. Carry-and-Forward technique is used for buffering the message if there is absent the appropriate intermediate node until get chance to come new node enter in the network to fill up the communication gap to forward the data packet. In traditional routing and forwarding protocol always consider the vehicular network is fully connected and if the connectivity of node breaks down then fail to deliver data for this sparse and opportunistic environment. These routing protocols have cooperated vehicular traffic on a big scale, supposing intense mobility of vehicular nodes and link with uninterrupted connection. The aim of the routing protocol in VANETs is to established end-to-end connectivity among the vehicular nodes so that an uninterrupted path may always exist; the case is always considered as non-DTN. Therefore the routing protocol in sparse or partially connected network when there is lack of intermediate vehicle to forward the data if use -carry-and-forward mechanism of DTNs to deliver data (Mangrulkar & Atique, 2010). This technique is based on the principle of that the end-to-end transmission path exists over time. Based on the methodology used to find destination routing in DTN can be classified into information based forwarding, geographic based forwarding, random forwarding etc. these categories may be significantly overlapping. Example of DTN routing algorithm are VADD (J. Zhao & Cao, 2006) and GeoOpps(Leontiadis; Ilias; Mascolo, 2007), SADV, GeoOpps and GPSR. There are very few protocols that work in low density VDTN. VANETs routing protocol which is suitable for DTN are present in the following.

Vehicle Assisted Data delivery Routing Protocol (VADD)

Because of the high mobility and unreliable nature of VANET, applying multi-hop data delivery tends to be more difficult. The main concept of VADD is based on the query and forward (Zhao & Cao, 2008). One of the vital issues is the choice of a forwarding path with limited packet delivery time and it follows some basic principles, which is to transmit maximum routing information through wireless channels and it must select the road with higher speed when the packet has to be carried through certain roads. As vehicular ad hoc networks have a very high probability of topology change so guaranteed packet delivery along the pre-computed optimal path is not assured, this is why the dynamic path selection should continuously be executed throughout the packet forwarding process. VADD routing algorithm has three modes of operation: Intersection, Straightway and the Destination, where every vehicle takes a choice at a junction and goes for next forwarding path depending on the operations. VADD is applicable in urban VANET scenarios and its operation requires no infrastructure. The data delivery rate as well as control packet overhead is high. The link establishment occurs through beacon messages.

Static-node Assisted Adaptive Routing Protocol in Vehicular Networks (SADV)

The SADV is used to eliminate the delay of message delivery in a sparse environment. The protocol utilizes some static nodes at road intersections in a completely mobile vehicular network to help relay data. The protocol allowed each node to calculate the time needed to deliver a message with the aid of a GPS system and digital map (Ding, Wang, & Xiao, 2007). SADV has three different modules; Static Node Assisted Routing (SNAR), Link Delay Update (LDU) and Multipath Data Dissemination (MPDD). SADV operates in two modes: “In Road Mode” and “Intersection Mode”. SNAR module stores and forwards packet through the best available path, LDU module effectively calculates the real time delay and MPDD reduces the delay. Practically, the deployment of static module at each intersection is not feasible.

Geographical Opportunistic Routing (GeoOpps)

Geographical Opportunistic Routing (GeoOpps) is a delay tolerant network routing algorithm that exploits the availability of information from the GPS in order to opportunistically route a message to a certain geographical location. It takes the advantages of the vehicles' GPS suggested routes to select vehicles that carry the information (Leontiadis & Mascolo, 2007). The model of selecting the next carrier is the neighbour vehicles that chase suggested routes to their driver's destination compute the nearest point that they will get to the destination of the message. Then they use the closet point and their map in a convenience function that expresses the minimum projected time that this message would need in order to reach its destination. The vehicle that can transmit the packet quicker/closer to its destination becomes the next packet carrier.

Greedy Perimeter Stateless Routing (GPSR)

The Greedy Perimeter Stateless Routing (GPSR) uses the beacon to select the node which is nearest to the final destination node (Karp & Kung, 2000). Firstly, it uses the greedy forwarding algorithm if it fail then it uses the perimeter forwarding algorithm for choosing a node through which a packet will proceed from source to destination. To forwarding the packet over the network a node requires to remember only one neighbouring node location. Dynamically choosing the path for forwarding the packets in the network. Characteristics of a high mobility node, the stale information of neighbour's position is stored in the sending node neighbour table. In the packet header, the information of destination node is stored and the header moves to the intermediate node and the information is never updated.

3.3.2.2 Non Delay Tolerant Network (non-DTN)

The non-DTN types of geographic routing protocols do not consider discontinuous connectivity and are only practical in highly congested VANETs. If there is no neighbour of a node in position based routing then forwarding strategy fails to deliver a packet and the situation is called local maximum. In this situation the routing protocol of non-DTN routing protocol performs a recovery strategy to deal with such a failure. The non-DTN routing protocol is further divided into a beacon, non-beacon and Hybrid. Example of Non-DTN overlay is CAR(Naumov & Gross, 2007), GSR(C. Lochert et al., 2003), A-STAR(Boon-chong Seet , Genping Liu , Bu-sung Lee , Chuan-heng Foh , & Lee, 2004), GPCR(Christian Lochert et al., 2005) and CBF are examples of non-DTN hybrid routing protocol.

Geographic Source Routing (GSR)

GSR (Christian Lochert, Mauve, Füßler, et al., 2005) is a position based routing algorithm that is uses location based information of neighbouring nodes. In GSR, the querying node floods the network with a 'position request' for a particular node. Upon receipt the node replies with a 'position reply' to the querying node. GSR uses extensive flooding and it has several extensions that address to minimize flooding. Such extensions require more processing at the cost of better performance. VANETs however, have superior processing and storage for such algorithms. GSR is a broad position based non-DTN routing protocol and its application scenario is urban area. Similar to all position based routing protocols it doesn't need any virtual infrastructure. The data delivery rate of GSR is low whereas the control packet overhead is moderate. The link type of GSR is beacon and path states with propagation model is road blocking.

Connectivity-Aware Routing (CAR)

The Connectivity-Aware Routing (CAR) protocol divided into four main parts. They are (1) destination location and path discovery; (2) data packet forwarding along the found path; (3) path maintenance with the help of guards; and (4) error recovery. The protocol combine locating destinations with finding connected paths between source and destination as a substitute of using the popular location service like RLS (Naumov & Gross, 2007). Each node regularly broadcasts HELLO message including its velocity vector (moving direction and speed). The beaconing period is dynamically changed according to the number of the registered nearby neighbours so the mechanism can adapt to the changing traffic conditions. The forwarding node evaluates link connectivity by calculating some metrics including hop count and average number of neighbours. The destination selects the path that provides better connectivity and lower delays by computing metrics using anchor point information recorded in the received routing request packet and unicast reply packet including the collected information as well as its position and velocity vector to the source node. A distinguishing property of CAR is the ability to not only locate the destinations but also find connected paths between source and destination pairs.

Geographic Routing in City Scenarios (GPCR)

Greedy Perimeter Coordinator Routing (GPCR) is another position-based routing protocol. It makes the use of the planar graphs. The streets and the junctions in city form planar graphs. Instead of using the static street maps or any other global or external information like the one used in A-STAR and GSR, GPCR makes the use of the natural planar graphs formed by the streets and junctions (Christian Lochert, Mauve, Füßler, et al., 2005). GPCR consists of two parts: a restricted greedy forwarding procedure and a repair strategy and junctions. A GPCR follows a destination based greedy forwarding strategy, routing messages to nodes at intersection. Since GPCR does not use any external static street map so nodes at intersection are difficult to find. GPCR uses a heuristic method for finding nodes located at intersections and designates those nodes as coordinators. GPCR proposed a repair strategy based on the topology of streets and intersections for adjusting the routing path. GPCR forwards data packets based on the node density of adjacent roads and the connectivity to the destination. Thus, if the density of nodes is low or there is no connectivity to the destination, then the delay time increases and the local maximum problem go unresolved.

Anchor-Based Street and Traffic Aware Routing (A-STAR)

A-STAR is also a position-based routing protocol which is mainly design for inter communication system in a city scenario (Seet et al., 2004). By using the vehicular traffic bus the ratio of connectivity of packet delivery is very high between end-to-end connections. A-STAR determines the end-to-end connection for low density traffic. By contrasting the greedy approach of GSR and the perimeter mode of GPSR, ASTAR uses the new local recovery strategy which is more acceptable for city scenarios. The A-STAR in which the path selection procedure ensure that the connectivity between nodes is very high and packet delivery ratio is low as compared to GSR and GPSR. The path selection strategy uses the static information to maintain the path between nodes which is based on the city bus routes which causes the connectivity problem on some section of streets.

3.3.2.3 Hybrid

The hybrid type of geographic routing protocols combines the non-DTN and DTN routing protocols to exploit partial network connectivity. GeoDTN+NAV(Cheng;, Lee;, & Gerla;, 2010) is a hybrid position base routing protocol.

GeoDTN+NAV

GeoDTN+NAV (Cheng, Lee, Gerla, & Härri, 2010) is a hybridization of non-DTN and DTN routing approaches that combines the greedy mode, the perimeter mode, and the DTN mode. The concept of the GeoDTN+NAV is that nodes belong suspecting with the network is disconnected based on the number of hops packet has travelled in the perimeter. It also measures the distance travelled by the packet so far, delivery rate and neighbour's direction with respect to the destination. GeoDTN+NAV is applicable in urban areas as a pure adhoc protocol. The data delivery rate and control packet overhead are both moderate. It uses beacon messages for path establishment and can use the road blocking propagation model.

3.3.3 Cluster Based Routing Protocol

In cluster based routing, each network is partitioned into interconnected sub networks. Each sub network is called a cluster. Each cluster has a cluster head (CH) as coordinator within the substructure. Each CH acts as a temporary router within its zone or cluster and communicates with other CHs. Hence, each cluster has one cluster head and the cluster is identified by the head cluster ID. Every node in the cluster is uniquely identified by a string called Node ID. A host in the cluster maintains a bi-directional link with the head of the cluster. LORA-CBF(R. A. Santos, A. Edwards, R. M. Edwards, & N. L. Seed, 2005) CBLR and CBDRP are the example of cluster based routing protocol.

Location Routing Algorithm with Cluster-Based Flooding (LORA-CBF)

LORA-CBF (R. A. Santos, A. Edwards, R. Edwards, & N. L. Seed, 2005) is a cluster based geographic reactive protocol which tries to find a route to its destination through position based information whenever a route is needed. It also introduces gateways between clusters to reduce the amount of broadcast data; only control messages are sent through broadcast. The protocol is similar to some of the cluster based protocols in MANETs. It creates cluster heads and gateways by implementing simple Hello beacons, REQ/REP messages and the timers. Routing tables are used within a cluster head and every other node knows its relative position within a cluster through GPS. However, using this protocol in the intermittent VANET scenario can be inefficient with very few nodes and clusters. Moreover, performance metric of this protocol related to cluster formation time is high in VANETs. LORA-CBF can run in intermittent connectivity scenarios by introducing cluster based communication. It has two-ray grounded propagation model and has moderate overhead and low packet delivery ratio.

Cluster Based Location Routing (CBLR)

CBLR is a cluster based, reactive and on demand routing protocol. In this protocol, each cluster head contains its own routing table in which is stored the addresses and locations of the all cluster members in the network (Santos, Edwards, & Edwards, 2004). Cluster header also keeps the information about all neighbouring clusters in the Cluster Neighbour Table (CNT). When the packet transmits between source and destination in the network then the source node firstly send the packet to the nearest neighbour of the destination if it is in same direction/cluster. If the destination is not in same cluster then the packet stores in the buffer then the Location Request (LREQ) packet broadcasting and start the timer. This protocol is more suitable for high mobility network. A digital road map is used to transmit the packets over the network. The packets transmit in the same cluster due to this reason the overhead of control packet is low. The number of transmission is more because this protocol is used for huge network.

Cluster-Based Directional Routing Protocol (CBDRP)

CBDRP is mainly designed for vehicles which are going in the same direction (T. Song, Xia, Song, & Shen, 2010). Firstly, the source node passes the packet to the cluster header then cluster header passes the packet to same cluster which is in same direction. A cluster header has the main responsibility to forward the packet to destination cluster. This protocol perform same as CBR but the direction and velocity of the vehicle are noticed when the packet forward to the cluster. With the help of CBDRP link stability problem resolved in the VANET. Data transfer in the network through clusters is more reliable and rapidly. During the packets transmit in the clusters; the control packet overhead is low. This protocol is more reliable for transmission the packets due to this the number of retransmission is more occurred.

3.3.4 Geocast Routing Protocol

Geocast refers to the delivery of information to a group of destinations in a network identified by their geographical location. It is a specialized form of multicast addressing used by some routing protocols for ad-hoc networks. All protocols have in common that they enable transmission of a packet to all nodes within a geographic region. In contrast to multicast, which enables a packet to be sent to an arbitrary group of nodes, a geocast group is only defined by a geographic region. Example of Geocast routing protocols are ROVER(M. Kihl & al, 2008), GV-Grid and DTSG.

Robust Vehicular Routing (ROVER)

ROVER (Kihl, Sichitiu, & Joshi, 2008) introduces a concept similar to Zone in FSR called Zone of Relevance (ZOR) and a message format that initiates route discovery. However, ZOR is considered to be an application specific zone apart from being in a node's transmission range. ROVER only broadcast during passing control messages and uncast otherwise for data packets. ZOR is created at the time of route discovery by sending a Zone Route Request (ZRREQ) message with three parameters i.e. application (A), message (M) and zone of relevance (Z). Traversal of these messages creates a tree among the nodes within a specific ZOR. There is another zone called Zone of Forwarding (ZOF), which includes all the nodes participating in the routing process including source node. This zone ensures that a vehicle only receives and accepts a ZRREQ if it exists within a specific ZOF. A node in ZOF replies by sending a Zone Route Reply (ZRREP) to the neighbouring node that sent ZRREQ. Most of the VANET routing protocols apply to urban areas but geocast routing is pertinent in highway scenario. ROVER is most suited for infrastructure less highways. The delivery rate of ROVER is high along with control packet overhead.

Inter-Vehicle Geocast (IVG)

IVG is also designed for a highway which is used to distribute the safety messages to vehicles on highways (Benslimane & Bachir, 2003). For forwarding the messages in network, it is used the timer based mechanism. For overcoming the network fragmentation periodic broadcasting technique is used.

Dynamic Time-Stable Geo cast Routing (DTSG)

The DTSG routing is mainly designed for the sparse density networks (Rahbar, Naik, & Nayak, 2010). Two phases followed by this protocol: Pre-stable phase helps to distribute the messages within the region and stable-period transitional node use to store and send procedure for a predefined time with in the region. Number of transmission processed high due to overhead. In this protocol dynamically adjust the network density and vehicle speed for better performance.

3.3.5 Broadcast Routing Protocol

Broadcast routing is suitable for sharing information about traffic, weather and emergency road conditions among vehicles. In broadcast routing, a node of the network disseminates a message to the vehicle beyond its transmission range through the use of multi hops. Broadcasting sends a packet to all nodes in the network, typically using flooding. This delivery consumed more bandwidth (Sandhaya Kohli, Bandanjot Kaur, & Sabina Bindra, 2010) because of duplicate message reception and disseminated messages collide due to congestion. It performs better in the sub-urban and highway where a small number of nodes take part in the network. The various Broadcast routing protocols are BROADCOMM (N. Ntlatlapa, 2008), Urban Multi-hop Broadcast protocol (UMB)(khan Korkmaz & Eylem Ekici, 2004) and DV-CAST(O. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, & V. Sadekar, 2007).

BROADCOMM

In BROADCOMM, a hierarchical structure of highway is simulated and the whole region is divided into virtual cells (Ntšibane Ntlatlapa, 2008). Cell members establish a hierarchy of Cell Reflector (CR), which acts like a base station to gather messages for particular cells as well as from neighbouring cells. CR helps in making judgements in relation to forwarding the messages to individual vehicles. This protocol has shown an improved performance in message broadcasting, delay and routing overheads when compared with other broadcasting protocols. In a probabilistic broadcasting approach is designed to mitigate broadcasting storms in dense VANET in order to transmit emergency messages effectively. The authors studied a weighted p-persistent routing scheme which shows better accessibility of the farthest node. The performance of this protocol depends on a reasonable choice of the number of nodes in the environment.

Urban Multi hop Broadcast Protocol (UMB)

UMB is mainly designed to solve the collision problem and hidden node problems through message distributed in the multi hop broadcast (Korkmaz, Ekici, Özgüner, & Özgüner, 2004). In this protocol without use any prior topology information the sender node tries to select the furthermost node in the broadcasting direction for sending and acknowledging the packet. The performance of UMB is better in higher packet loads and vehicle traffic density scenarios. The advantage of this protocol is that it will overcome the problem of packet collision and hidden node problems. Main disadvantage of this protocol is that it wastes the lot of bandwidth.

Distributed Vehicular Broadcast Protocol (DV-CAST)

DV-CAST (Z. Tonguz, N. Wisitpongphan, F. Bai, P. Mudalige, & V. Sadekar, 2007) is a completely distributed protocol designed for different types of connectivity scenarios in VANETs i.e. high connectivity, intermittent connectivity and no connectivity. Local topology information in DV-CAST is significance in the routing process. It used in finding whether a vehicle is the referred receiver; vehicle has a connection to another vehicle or determine the position of a vehicle in a cluster. Routing is based on certain parameters i.e. Destination Flag (DFlg), Message Direction Connectivity (MDC) and Opposite Direction Connectivity (ODC). These messages correspond to the state of a receiving node and to the type of connectivity. DFlg is used by nodes to check whether the message is duplicate or new. Value of MDC and ODC is checked to see the nature of connectivity in a VANET. For instance, if MDC and ODC correspond to zero then the vehicle is completely disconnected from the network. DVCAST has fewer hello messages and number of broadcast messages within a cluster decreases collisions and duplications. DVCAST suffers from low delivery rate due to its distributed nature and high packet overhead. Its link type is categorized as broadcast and propagation model as road blocking.

3.4 Discussion

The objective of a routing protocol is to guarantee a reliable and efficient delivery of packets. Each routing protocol for VANET has different features and requirements, suited for different vehicular traffic scenarios. The comparison of various routing protocol types is given below in a tabulated form in terms of application scenario, virtual infrastructure, delivery rate, control packet overhead, link among node and propagation model (Cenerario, Delot, & Ilarri, 2008; Takano, Okada, & Mase, 2007; Tee & Lee, 2008; Trivedi, Veeraraghavan, Loke, Desai, & Singh, 2011; Wai, Guha, Taek Jin, Lee, & Hsu, 2008). From the table it is indicated that most of the routing types are applicable in urban areas. Geocast and Broadcast routing algorithms apply to highway scenarios. None of the routing algorithms require virtual infrastructure except for cluster based algorithms. The packet delivery rate of non-DTN, cluster and broadcast algorithm is low and position based GeoDTN+NAV is moderate. All other routing algorithms have a high packet delivery rate. The control packet overhead is very high for proactive, DTN, geocast and broadcast VANET routing algorithm and reactive type have low control packet overhead but other routing algorithms have moderate control packet overhead. Link among nodes can be path states, beacon, data broadcast and single hop or multi-hop and the propagation model of the routing protocol can be probabilistic or road blocking.

Table 3.1. Analysis of VANET routing protocol in terms of performance metric

Protocol Type		Protocol Example	Application Scenario	Virtual Infrastructure	Delivery Rate	Control Packet overhead	Link	Propagation Model
Topology	Proactive	DSDV, OLSR, FSR	Urban	No	High	High	Path states	Unknown
	Reactive	AODV, DSR, TORA	Urban	No	High	Low	Path states	Probabilistic
	Hybrid	ZRP	Urban	No	High	Moderate	Path states	Probabilistic
Geographic	DTN	VADD, SADV, GeoOpps, GPSR	Urban	No	High	High	Beacon	None
	Non-DTN	CAR, GSR, GPCR, CBF	Urban	No	Low	Moderate	Beacon Path States	Road blocking
	Hybrid	GeoDTN +NAV	Urban	No	Moderate	Moderate	Path states and beacon	Road blocking
Cluster		LORA-CBR, CBLR, CBDRP	Urban	Yes	Low	Moderate	Data broadcast	Two- Ray ground
Geocast		ROVER, GV-Grid, DTSG	Highway	No	High	High	Hop	Unknown
Broadcast		BROADCOMM, DV-CAST, UMB	Highway	No	Low	High	Data broadcast	Road blocking

3.5 Motivation for Delay Tolerant Network in VANETs

The main focus of our research is a special type of VANETs, where vehicular network is sparse and frequent disconnection is very common so the direct end-to-end transmission between the communication parties may not always exist. Therefore the communication in this context define as the DTN in vehicular environment which sometimes called Vehicular Delay Tolerant Network (VDTN) (Kurhinen & Janatuinen, 2008). As the RSU have limited transmission range, the node in VDTN may not communicate to the RSU directly and therefore the intermediate vehicles relay for the packet transmission on to rely node (Gil-Castineira, 2007). Complete end-to-end communication path may not exist in a sparsely connected network during the message relay process (Soares, Rodrigues, & Farahmand, 2012). Hence the forwarding process take place using buffering of intermediate vehicles. The buffering process hold the packet until the transmission node found, upon found a neighbour in the transmission range immediately deliver the packet. The main goal of the routing protocol in DTN is to maximize the transmission efficiency by delivery the highest ration of packet to the destination at low end-to-end delay with low control overhead. The performance of DTN routing protocol is closely related to vehicle density and mobility model of network so the vehicular traffic model are also important. For the feasibility of many applications in VANETs, it is imperious to design routing protocol that can overcome problems that arise from sparsely connect VANETs environments. These vehicular nodes in DTN have very short contact duration or move an unpredictable way; so the creation a short lived link with high link error rates and the lack of an end-to-end transmission path from the source to destination. Therefore produce a partitioned vehicular network environment, due to the variable vehicular densities and sparse traffic, results discontinuities along the path from source to destination. Almost all the traditional VANET routing protocols were designed for VANETs considering a fully interconnected network, aiming to establish end-to-end transmission among vehicular modes. However these routing protocols should not be appropriate when the vehicle density is quiets down. End-to-end transmission link via rely nodes may not be established any more. So this type of routing protocol unable to deliver data opportunistic partitioned and sparsely connected vehicular network. To address this problem VANETs, need a dynamic technique for data delivery using the carry-and-forward (SCF) for DTN rather than a simple carry-and-forward method. In DTN connection between nodes perform without previous prior information, and so the challenges that DTN need to overcome have led to significant research focused on routing of VDTN borrowed some unique characteristics from both DTN and vehicular network which should be consider when designing network routing for them.

3.6 Conclusion

VDTN is a kind of special VANETs where delay tolerant or delay bounded technique is used to address the problems such as network partitioning, frequent disconnection etc. DTN technique can be applied to a broad class of networks where is absence of guarantee of end-to-end connectivity. VANETs may suffer from same types of problems of the high mobility of vehicles, which communication with each other or with RSU and the condition are characterized by long-variable delays, latencies and intermittent connectivity, end-to-end route may never exist at certain time and there can be high error rates. For example, such condition is found in scenario with sparse vehicular density. In DTN vehicular node carry-and-forward network data while waiting for opportunities to forward it the DTN is differ from other non-DTN approach as the vehicle in DTN used to carry the data towards the destination even absence of neighbour node. The carry-forward of data is done by the use of special node; called relay node and terminal node. Terminal nodes can be located in isolated regions and they can provide internet access for the DTN. Relay nodes allows the vehicle to upload and downloads when there is no other alternative. Traditional routing and forwarding protocols used in the case of fully connected VANETs fail to deliver data in DTN environment. In conventional VANET, routing protocols are appropriate for non-intermittent and dense network routing. Those traditional routing fail to deliver data in sparse, partitioned and opportunistic environments. Most of the routing protocols that have been developed for VANET are assumed that there are a high number of nodes available in the network to act as relay nodes. However this postulation is unrealistic in the most cases, because in many situations number of nodes will be very low either along the road or in some sections of the road, this will reduce the packet delivery ratio and increase dropping packets. As a result, this will degrade the network performance. Therefore the focus of this thesis is on the DTN type rather than the non-DTN network type. The delay tolerant routing protocol is the best solution for the low density network on a large scale, intense mobility of vehicles and connections without link breakage. Routing protocols in VANETs aim to establish end-to-end connectivity among network nodes through some path, which is the case of a delay tolerant environment. Hence, routing protocols in DTNs use the carry-and-forward paradigm of DTNs to deliver data.

CHAPTER 4: FRAMEWORK FOR ADAPTIVE DTN ROUTING IN VANETS

4.1 Introduction

VANETs consist of vehicular nodes that are capable of establishing connectivity via multichip wireless communication that does not rely on any centralized control or infrastructure. This freedom from the requirement for any fixed infrastructure allows ad hoc networks to be instantly deployed and hence makes them very useful in cases when immediate communication facilities are required. In VANET regular change of motion of nodes produce a high rate of change in the topology. If a node is in the vicinity of the communicating node then the communication between nodes is accomplished by one radio hop direct communication. However, when the nodes are far apart it may be necessary for the packet to travel through two or more hops in order to establish indirect communication between nodes. In indirect communications, packets must be forwarded by intermediary nodes in the direction of the destination node. VANET based routing protocols must be adaptive in order to deal with the changes in topology and must also have low network overhead because of their limited link capacity. The development and deployment of VANETs have been highly motivated by their intended real life functionality. VANETs allow messages to be communicated between vehicles in an ad hoc network formation. The nature of messages in a vehicular environment dictates the priority that should be assigned to their handling. For example, a message concerning a safety issue that is being relayed by a vehicle that has been in an accident on a main highway should receive priority for broadcasting to all other vehicles in the region. On the other hand in discourse between the nodes the messages should be routed toward the destination node in order to overcome the problem of fragmentation of the ad hoc network. The broadcast operation plays a fundamental role in a VANET and has both positive and negative effect. The positive effect stems from the fact that whenever a message is transmitted by a vehicle, it is received by all vehicles within broadcast range of the sender. The negative effect results from possible interference with other communications. Beaconing provides a method of disseminating messages to all the nodes in the network but it may also trigger a broadcast storm that can overload the network. A broadcast storm can be avoided through the use of efficient and controlled adaptive beacon schemes that aim to reduce the number of retransmitting nodes, which then in turn reduced network traffic while ensuring that the intended nodes do receive the message. Although geographic protocols are relatively free from the problems that limit the use of topology based protocols for VANETs, in practice, the deployment of VANETs remains restricted subject to the resolution of several important challenges.

In this chapter, we first present the research methodology of developing adaptive geographic delay tolerant network routing in vehicular environment. A framework for the adaptive DTN routing also presented. At next, we introduce system model to implement adaptive delay tolerant routing. We present vehicular mobility models and introduce mathematical analysis of performance metric for DTN.

4.2 Research Methodology

The methodology components in this thesis are described as follows:

i) Background Study: A detail of vehicular technology, VANETs characteristics, application and vehicular communication details, VANETs challenges and requirements are given in chapter 2.

ii) Literature Review: Review the state-of-the-art VANETs routing protocols, finding the gaps in DTN in VANETs, define the problem statements are discuss in chapter 3.

iii) Proposal: We proposed an adaptive DTN framework in vehicular environment, which is the first framework in this research area, is proposed taking into account the major parameter of partially connected VANETs to solve problems those find in investigation.

iv) Implementation: Our proposed adaptive DTN framework uses position information of vehicular node by GPS, present direction and predicted future direction acquired by DIL and current vehicular speed utilizes delay tolerant vehicular networks for real-time data gathering. As the DTN suffers from frequent network disconnection due to the density of vehicular network, lack of central coordination, dynamic topology, high mobility of node and the limited resource availability experimentation and performance evaluation of our proposed framework can be done via simulation tools. It is very expensive and very hard to complete the real test-beds construction for any vehicular networks environment due to testing area, mobility and number of nodes consider. To overcome these problems in VANETs we used simulations tools.

v) Analysis and comparing the result with a benchmark: In this step, extensive and various simulation runs and tests are carried out to examine and comparing the result of our proposal compared with other existing DTN routing protocol in vehicular environment. In addition, best values for newly developed adaptive DTN framework in VANETs and routing protocol variables are determined through the simulation runs. Different simulation scenarios such as vehicle densities, data packet size are considered in order to comprehensive comparison between our proposal and existing solutions. For the comparison and performance evaluation the metrics used are packet delivery ratio, overhead and end to end-to-end delay.

The following figure-4.1 depicted the approach of research methodology used in this thesis.

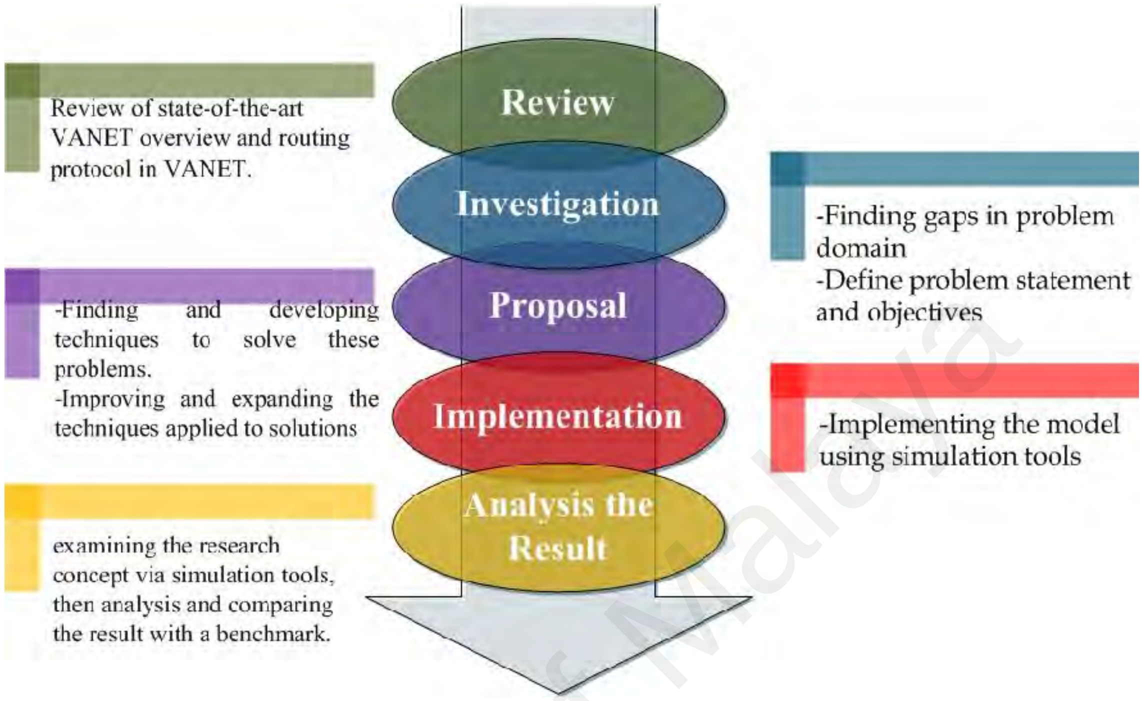

Figure 4.1: Research Methodology

4.3 Framework for the Adaptive DTN in VANETs

To develop an adaptive routing protocol for delay tolerant network in vehicular environment, we need to propose a novel framework which is easy to demonstrate, accessible and detailed enough to understand. The basic architecture describing the framework is composed of several parts with distinct predefined functions. Each layer is capable to receive the input and send the output to bellow or upper layer. The advantages and viability of this approach effectively used in many existing system in present days such as TCP/IP family of protocols (Fall, 2003). Each layer is very simple rather than the model as whole and easy for development (Jarupan & Ekici, 2011). Each module of the framework is different in terms of its functionally and semantics. To define the specialized validation routines on each module for analysis specific properties of the framework based on characteristics of its essential components. The framework is sort of a model can be represented with several independent module which communicate via simple interfaces.

In this section, a novel framework for OBU in VANET is introduced for the adaptive VDTN network. This framework consists of four main modules as sensing unit, processing unit, node discovery unit and DSRC standardized by IEEE802.11p. The sensing unit collects external different vehicular parameter values for the further processing in the application layer where produce compatible data for the network layer. Node discovery unit in the network layer takes the responsibility for the neighbour discovery. The next-hop selection algorithm in the network layer finds the appropriate intermediate node ID to transmit the message. The following Figure 4.2 shows the framework for adaptive VDTN routing.

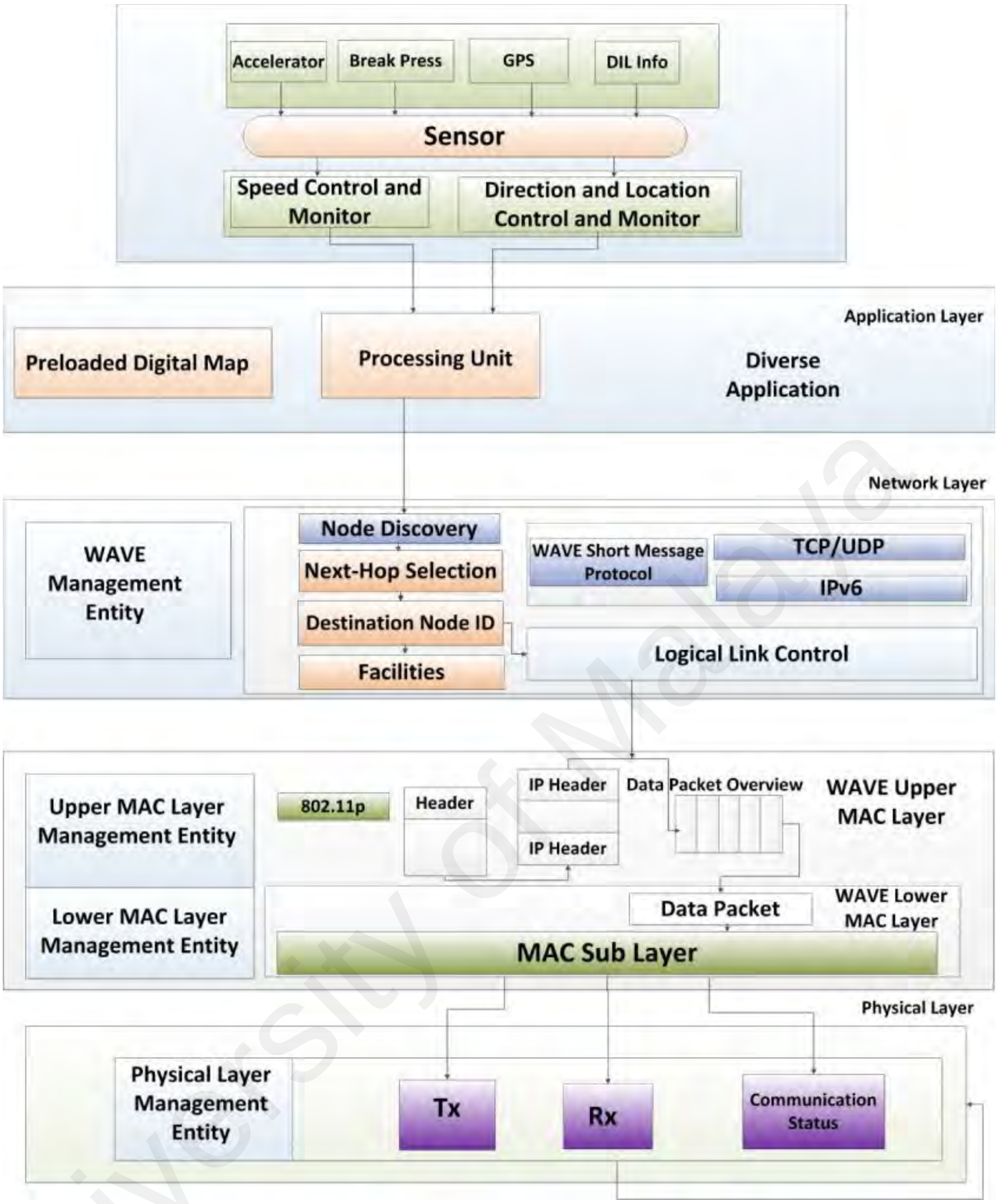

Figure 4.2: Framework for adaptive DTN routing in VANET

4.3.1 Sensor Unit

The sensor unit is required to gather and provide information about its various situations. Accessing the data from in-vehicle sensors is possible now-a-days using the On Board Diagnostics (OBD) standard interface (Jarupan & Ekici, 2011), which serves as the entry point to the vehicle's internal bus. This unit is responsible for periodically collecting data from the different sensors available in the vehicle, converting them to a common format, and providing the collected data set to the OBU. The sensor unit collects the data from the different sensor fitted in the vehicle for further processing. This data may affect vehicle circumstances such as the vehicle position and vector information.

4.3.1.1 Velocity Knowledge

The velocity knowledge can be obtained by exploiting sensors fitted on a specific vehicle parts that can senses the change in vehicle speed. The brake sensor sense if the driver presses the sudden brake; then transmit this information to the Speed Control and Monitor Unit (SCMU) in the vehicle OBU.

4.3.1.2 Direction Information

The direction knowledge can be acquired from the GPS and DIL of the vehicle system. The vehicle predicated future direction is derived from the digital road map and DIL information.

4.3.2 Processing Unit

A processing unit is responsible for processing the data from sensors and determining the different vehicle parameters. The information from the vehicle is gathered, interpreted and used to determine the vehicle's current status. This unit must have access to a positioning device (such as a GPS receiver) and access to different wireless interfaces. Thereby, enabling communication between the vehicle and the remote control centre.

4.3.3 Node Discovery Unit

The node geographic position, vector information and predicted future direction are continuously observed. If any parameter value changes significantly then instantly send a HELLO beacon message to the surrounding vehicle. The node discovery unit is responsible to send adaptive HELLO beacon message.

4.3.4 DSRC/WAVE Control Unit

DSRC is a 75MHz wide spectrum band at 5.9GHz allocated by the U.S. Federal Communication Commission (FCC) for exclusive vehicle-to-vehicle and infrastructure-to-vehicle communications. The allocation of the DSRC spectrum is primarily intended to support V2V and V2I Communication. DSRC is described in details in Chapter 2.

4.3.5 HELLO Beacon Message for the Adaptive DTN

In geographic routing neighbour discovery is done by broadcasting the HELLO beacon message. The HELLO beacon packet contains the information about the node current position, vector and DIL information. The nodes in the VANET updates about their neighbour by periodic broadcasting of HELLO beacon message. This periodic broadcasting produces latency in urban areas. Therefore broadcasting this HELLO beacon message generate an excessive packet overhead and waste a major part of bandwidth. Bandwidth consumption is one of the major limitation and heavy load being generated on it; which will increase the collision, contention and packet overhead (Yassein, Nimer, & Al-Dubai, 2011). As bandwidth is very limited for VANETs applications, the fair use of bandwidth has an impact on reducing the time delay for transmitting messages. To overcome this limitation a novel method has been developed in this thesis, which broadcast the vehicle specific information adaptively when it required based on the some specific parameter rather than fixed time interval. This adaptive HELLO beacon procedure reduces the excessive control packet which improves the network performance. The procedure for the adaptive HELLO beacon message in the DTN is shown in the framework.

4.4 Adaptive Geographic DTN Routing (AGDR) Model Definition

This section describes the model definition for the proposed adaptive geographic vehicular delay tolerant routing, formulation of the assumptions of the system model, represents the mobility model and traffic model.

4.4.1 System Model Assumptions

To achieve the objectives behind developing an adaptive delay tolerant routing in vehicular environment, some assumptions need to be agreed on to fulfil the requirements. Each vehicle is equipped with a set of devices, which are considered to be available on the vehicles at the present time. These contain the OBU, digital road maps, and navigation system. Each vehicle equipped with OBU system collects its own traffic information, including location, spacing, velocity, acceleration etc., from navigation system. (Coelho & Rouphail, 2010). It is also able to communicate with other vehicles equipped with IVC system by DSRC. In ITS technology, a number of sensors are installed in the road section to determine the vehicle density, traffic flow rate and the vehicle mean speed. The next section covers the mathematical model which shows how to calculate the vehicle density, traffic flow rate and the vehicle mean speed (Buslaev, Gasnikov, & Yashina, 2012; Dhingra & Gull, 2008).

4.4.2 Mobility Model

Vehicle movement adheres to the physical road topology and mobility is hard to control through a centralized system. Due to the high mobility in VANETs, the topology tends to change frequently. Our assumptions are based on the urban environment model; that is vehicles in urban area have minimal difference in their relative speeds. Therefore, vehicles can have a well-connected state as well as prolonged disconnection on a single lane. So the vehicles can experience frequent disconnections for minimal durations. The proposed protocol assumes the urban scenario with organized and predictable movement in two lane scenarios. The performance of application and protocols in a VANET are strongly influenced by the vehicle mobility (Gozalvez, Sepulcre, & Bauza, 2012). Hence in a VANET it is very significant the network model considering the specific mobility patterns. The mobility model is designed to describe the movement pattern of vehicle on roads, and how their location, velocity and acceleration change over time. Since mobility patterns may play a significant role in determining the protocol performance, it is desirable for mobility models to simulate the movement pattern of targeted real life applications in a reasonable way. Otherwise, the observations made and the conclusions drawn from the simulation studies may be misleading. Thus, when evaluating VANET routing protocols, it is necessary to choose the proper underlying mobility model. Random Way Point Mobility Model is used in this research simulation.

For modelling a urban scenario with a random dense road pattern on a limited area of a few square kilometres, the Random Way-Point (RWP) mobility model is commonly used for approximation (Wischhof, 2007). In random-based mobility models, the vehicular nodes move randomly on the road. To be more specific, the destination, speed and direction are all chosen. This kind of model has been used in many simulation studies. The Random Waypoint Model was first proposed by Johnson and Malt. Soon, it became a 'benchmark' mobility model to evaluate the VANET routing protocols, due to its simplicity and wide availability. In the network simulator (ns-2) distribution, the implementation of this mobility model is as follows: As the simulation starts, each vehicular node randomly selects one location in the simulation field as the destination. It then travels towards this destination with constant velocity chosen uniformly and randomly from [0,V], where the parameter V is the maximum allowable velocity for every vehicle. The velocity and direction of a vehicle are chosen independently of other vehicle. Upon reaching the destination, the vehicle stops for a duration defined by the ‘pause time’ parameter. If T =0, this leads to continuous mobility. After this duration, it again chooses another random destination in the simulation field and moves towards it. The whole process is repeated again and again until the simulation ends.

To focus the network topology and reception situation at every moment in time the location of the vehicle is utilized. This combination of vehicular traffic and network simulation allows a detailed modelling of the network topology at a moderate computational complexity. A wide range of vehicular network scenarios can be evaluated by variation of the parameters. Due to the high speed and mobility of vehicles the topology is very dynamic and the short range of inter vehicular communication results in frequent disconnections (Benamar, Singh, Benamar, El Ouadghiri, & Bonnin, 2014). For example, imagine two cars coming from opposite directions and meeting each other at 100 km/h: the window of communication opportunity is just a few seconds and after that there will be disconnection. This disconnection duration increases when traffic density is low, as in the case of VDTNs. Operating environments also vary, ranging from highly dense freeway, where ad hoc networking concepts can be applied, to urban areas with sparse traffic. With GPS capabilities it is possible to locate different vehicles. In addition given the speed and the fixed trajectories enforced by highways and street maps, it is possible to predict the future location of a vehicle. Thus, mobility models that can predict the future position of smarter nodes can help in making optimal routing decisions. Mobility models need to take into account several things such as street conditions, vehicle speed and statistics such as density of vehicles and obstacles such as buildings.

4.4.3 Vehicular Traffic Model

Routing performance for DTN is directly influenced by the node density. Moreover, vehicular node density plays an important role in route selection and repair in DTN (Zuo, Wang, Liu, & Zhang, 2010). Vehicular node density is defined as number of vehicle through a road section at a specific time. Considering the radio propagation range of vehicular node. It is very important to predict the level of connectivity for the vehicular network. Network connectivity plays a vital role on the routing protocol performance.

4.4.3.1 Vehicle Density

Vehicle Density ° referred to the number of vehicles at location *S* in certain time interval can be measure for a road section with ΔX length as:

$$^\circ = \frac{n}{\Delta X} \tag{4.1}$$

The vehicle density ° varies with location and time. So considering those parameter equations (4.1) can be written as:

$$^\circ(x_1, t_1, S_1) = \frac{n}{\Delta X} \tag{4.2}$$

Where x_1 is the measured location, t_1 is the time interval and S_1 is the road section. The unit of the vehicle density is vehicles per kilometre. Now we can make a general form by multiplying the numerator and denominator of eq. (4.2) by a small time interval dt.

$$^\circ(x_1, t_1, S_1) = \frac{n.dt}{\Delta X.dt} \tag{4.3}$$

The numerator of eq. (4.3) is the total number of vehicle in S at time t and the denominator shows the area of the measurement interval S. So the vehicle density for a measurement interval S at location x and at time t as:

$$^\circ(x, t,, S) = \frac{\text{Total Number of Vehicles in S at Time t}}{\text{Area(S)}} \tag{4.4}$$

4.4.3.2 Vehicle Flow Rate

Vehicle flow rate is the number of vehicles that pass through a certain road section per time unit. The vehicle flow rate Φ at location x_2, a time interval ΔT of measurement interval S2 can be defined as follows. For a time interval ΔT at any location x2, the flow rate is:

$$\Phi(x_2, t_2, S_2) = \frac{m}{\Delta T} \tag{4.5}$$

The number m is the total number of vehicles that passes through the location x2 during ΔT. The unit of vehicle flow rate is vehicle per hour. Multiplying the numerator and the denominator by a small location interval dx we find a more general form for vehicle flow rate. The numerator becomes the total distance travelled by all vehicles and the denominator is the area.

$$\Phi(x_2, t_2, S_2) = \frac{m.dx}{\Delta T.dx} = \frac{\text{Total Distance Covered by Vehicles in } \mathrm{S}_2}{\text{Area}(\mathrm{S}_2)} \tag{4.6}$$

From the eq (6) we can find the general definition for vehicle flow rate:

$$\Phi(x, t, S) = \frac{m.dx}{\Delta T.dx} = \frac{\text{Total Distance Covered by Vehicles in S}}{\text{Area(S)}} \tag{4.7}$$

S is the total distance covered by the vehicle.

The graph of vehicle flow versus hour provides information of traffic flow volumes and average speed of the transportation network during a selected time period of the day. This information is useful for analysing the historical performance of the transportation network and implementing proactive measures to improve the flow of traffic as well as in making a decision for green route selection.

Figure 4.3 shows a typical traffic flow versus time of day.

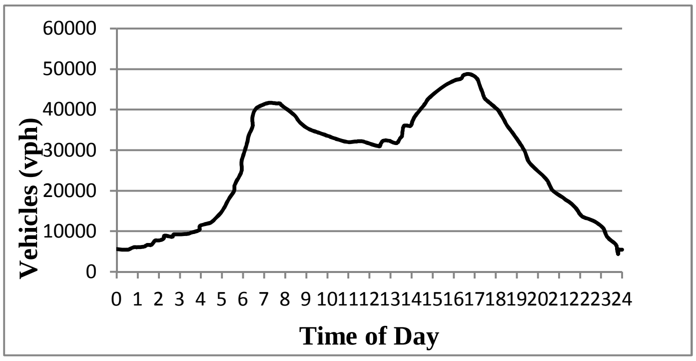

Figure 4.3: Typical traffic flow versus time of day

4.4.3.3 Vehicle Mean Speed

The vehicle means speed « can be defined as the average speeds of all the vehicles for a location in a certain interval. The mean of vehicle speed is dependent on location, time and measurement interval. The relationship with vehicle density and vehicle flow rate can be made as follows:

$$«(x,t,S) = \frac{q(x,t,S)}{k(x,t,S)} = \frac{\text{Total distance covered by vehicle s in S}}{\text{Total time spent by vehicle s in S}} \qquad (4.8)$$

From the eq. (4.8) the vehicle mean speed can be rewritten as the fundamental relation of traffic flow theory:

$$\Phi = {}^{\circ}.« \qquad (4.9)$$

This is the general relations among vehicle flow rate, density and mean speed. Using this equation, by knowing two of these variables easily find the third variable. The vehicle mean speed for total n vehicles in the interval S at location x and point in time t can be calculated as

$$«(x,t,S) = \frac{1}{n}\sum_{n} v_i \qquad (4.10)$$

From the equation (4.4) and (4.7) we can easily find the mean speed

$$\text{«}(x,t,S) = \frac{1}{\frac{1}{m}\sum_{m}\frac{1}{v_f}} \tag{4.11}$$

It shows that the node density depicts the network connectivity, so we can take necessary steps to prevent the network failure when the density of vehicle is low. In the process of road repair, if a vehicular node detects that link between itself and the next hop is broken, it may initiate to find alternate next-hop or store the packet until a new forwarding node is found.

4.5 Mathematical Analysis of performance metric for DTN in VANETs

The mathematical analysis for calculating packet overhead of DTN routing in VANET, end-to-end delay and message propagation is given bellow:

4.5.1 Mathematical Analysis for Packet Overhead for DTN in VANETs

Two parameters affect the routing overhead for DTN routing in VANET, there are number of neighbour vehicle and number of hops. Here we will calculate the routing overhead for the DNT network in VANETs using the probabilistic method. The distance from source vehicle to destination vehicle by the number of intermediate node relaying the data packet is the number of hops (Naserian, Tepe, & Tarique, 2005). Let say a VANET with n vehicle that are randomly distributed in a region with size $a \times b$ square meter. The radio transmission range of the vehicular node is l. So the dimension of the network are a and b meter where $a, b \gg l$.

Let the source vehicle is S and destination vehicle is D anywhere in the region of interest. We may calculate the probability of a random vehicular node A is place in the radio transmission range of node S the probability is p, and given by

$$p = \frac{\text{®} l^2}{ab} \tag{4.12}$$

If node $n-1$ is distributed in addition to node S in the region of interest the probability of having m neighbour of the node S can be found by equation

$$P_M(m) = \binom{n-1}{m} p^m (1-p)^{n-1-m} \tag{4.13}$$

In eq (4.13) m is a binomial random variable. As is S is random and any vehicular node in the VANET, $E[m]$ is symbolize the average number of neighbour vehicles for any node in the VANET. Therefore

$$E[k] = (n-1)p \tag{4.14}$$

So we should need to focus on the number of intermediate vehicular node for relay message from the source vehicle S to destination vehicle D. To achive such objective, it is enough to calculate the Euclidian distance d between any two random vehicular node S. The number of relay vehicle is k, and will be given by

$$k = \frac{r}{l} \tag{4.15}$$

Let say the position of the node S and D are $x_1, y_1$and x_2, y_2respectively. The arbitrary variables $x_1, y_1$and x_2, y_2 are free and consistently scattered between $0, a$ and $0, b$ in orderly. A random variable r is the distance between the nodes S and D and calculate interm of $x_1, y_1$and x_2, y_2 as $r = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$. We can assign $x = x_1 - x_2$ and $y = y_1 - y_2$ and rewrite $r = \sqrt{x^2 + y^2}$

The probability distribution function (PDF) of x, y can be found by

$$f_X(x) = \begin{cases} \dfrac{1}{a} - \dfrac{|x|}{a^2} & -a < x \le a \\ 0 & Otherwise \end{cases} \tag{4.16}$$

$$f_Y(y) = \begin{cases} \dfrac{1}{b} - \dfrac{|y|}{b^2} & -b < x \le b \\ 0 & Otherwise \end{cases} \tag{4.17}$$

As we know the PDF of x, y and let us assume $z = x^2$ and $w = y^2$ then PDFs of z and w found by the following

$$f_U(u) = \begin{cases} \dfrac{1}{a\sqrt{z}} - \dfrac{1}{a^2} & -0 < z \le a^2 \\ 0 & Otherwise \end{cases} \tag{4.18}$$

$$f_W(w) = \begin{cases} \dfrac{1}{b\sqrt{w}} - \dfrac{1}{b^2} & -0 < w \le b^2 \\ 0 & Otherwise \end{cases} \tag{4.19}$$

So we now find the PDF by interchanging the variable $u = l^2$ from the arbitrary variable z and w. Since z and w are independent the PDF of u is now found by

$$f_U(u) = f_Z(z) * f_W(w) \tag{4.20}$$

Here * stands for the convolution, and we may find the PDF of r by

$$f_r(x) = \begin{cases} 2x\left[\dfrac{\text{®}}{ab} - \dfrac{2x}{ab^2} - \dfrac{2x}{ba^2} + \dfrac{x^2}{a^2b^2}\right]; & 0 \le x \le b \\ \dfrac{2x}{ab}\left[\dfrac{\text{®}}{2} - \arcsin\left(\dfrac{\frac{x^2}{2} - b^2}{\frac{x^2}{2}}\right)\right] - \dfrac{4x}{ab^2}\left[x - \sqrt{x^2 - b^2}\right] - \dfrac{2x}{a^2}; & b \le x \le a \end{cases} \tag{4.21}$$

From this equation (4.21) we can calculate the Expected value of the number of hops, $E[l]$ and $E[k]$ as

$$E[r] = \int x f_r(x) dx \tag{4.22}$$

$$E[k] = \left\lceil \frac{E[r]}{l} \right\rceil \tag{4.23}$$

d is radio transmission range of the vehicular node. Our interest is to find the average number of overhead packet for the delay tolerant vehicular networks. The routing overhead is the number of control packet is propagated in the network. It consists of route request and route reply. To remove the redundancy of route request it will check the request id and sender address of that request. So in the worst case, when all vehicular hop in the VANET are connected and when there is no single vehicle in the network. For the first case $n-1$ route request packet propagates in the VANET for n vehicle for one communication pair. To minimize a single request broadcasting by a nodes use a parameter in the packet header and this parameter set a maximum value and this value is increase if the sender doesn't get any response. Hence the route request packet will propagate regularly up to the depth of $E[d]$ in the VANET. Figure 4.4 depicts a simple VANET with two nodes; node A and B with $(n-1)p$ neighbour on average but they also share some neighbour.

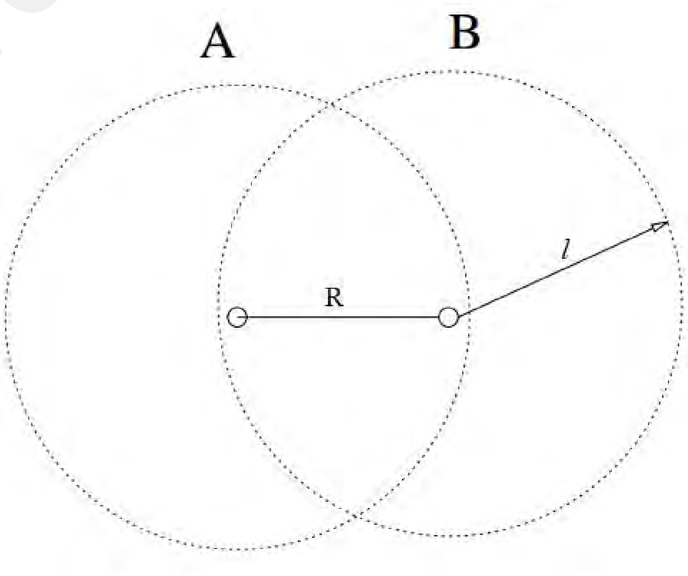

Figure 4.4: A simple VANET with two nodes

We may denote this radio transmission range of vehicle A and B as SA and SB, so the shared area of $SA \cap SB$. If we define R as the distance of two nodes, the intersection is

$$INTC(A, B) = 4\int_{R/2}^{d} \sqrt{r^2 - x^2}\, dx \tag{4.24}$$

Using the equation (4.23) and by integrating the value over the circle of radius x centered at A for area $SA \cap SB$.

$$E[INTC9A, B) = \int_0^l \frac{2\circledR x.INTC(A, B)dx}{\circledR l^2} \approx 0.59\circledR l^2 \tag{4.25}$$

So from the relation in (4.25) it is clear that the probability of the second hop have share the neighbours with the first hop is 0.59p. The sharing neighbours flooding the route request packet from first node A and according to the routing protocol it will not flooding again. If we remove the sharing neighbours from the average of neighbours $(n-1)p$, we see the effective number of neighbours for the second node B, which will participate in broadcasting we denote by m_2. So the average number of effective neighbours for random second node B is

$$E[m_2] = 0.41p(n-2) \tag{4.26}$$

Alternatively we can say the probability of finding new neighbour for the second hop B is 0.41p. We assume an extra coverage index when there are i node in the radio range of the sender node as C_i, where $C_1 = 0.41, C_2 = 0.19, C_3 = 0.09$ and $C_4 = 0.05$ C4=0.05. We assume N_1 as the number of neighbours of the originator or first tier neighbours. We can write:

$$N_1 = (n-1)p \tag{4.27}$$

So N_j can be define as the number of effective neighbours of the j^{th} level. Hence we find N_2 and N_3 as follows.

$$N_2 = \sum_{i=1}^{4} (n - N_1 - i) p.C_i \tag{4.28}$$

$$N_3 = 4 \times \left[\sum_{i=2}^{4} (n - N_1 - N_2 - i + 1) p.C_i \right] \tag{4.29}$$

In level three and higher, it is assume that there are three neighbour nodes on average that should give more efficient coverage. As the average route request pass to the depth of $E[k]$ in the VANET while not reaches to the destination, from the equation (4.28) and (4.29) we found the neighbours for the $E[k]^{th}$ level as

$$E_{E[k]} = 4 \times 3^{E[k]-1} \left[\sum_{i=2}^{4} \left[(n - 1 - i) - \sum_{j=1}^{E[k]-1} N_j \right] p.C_i \right] \tag{4.30}$$

We can easily find out the value of the expected value of the total number of broadcasts of the route request in the VANET as

$$E[Broadcasts] = \sum_{i=1}^{E[k]} N_i \tag{4.31}$$

Here N_i represents the number of neighbour in the level i that are connonected in the next level. Equation (4.31) can be used as lower number of overhead due to the number of route requests in VANET. As we know in a routing overhead consist of route request and route reply need to be calculated. The average number of route reply. The expected number of route reply from destination to the source can be found as follows

$$E[REPLY\ ] = (n - 4) p + 2 \tag{4.32}$$

In general the route reply of the message can be written as follows:

$$E[REPLY]=\begin{cases} E[k]+\dfrac{E[k]}{2}(n-E[k]-2)p & E[k] isEven \\ E[k]+INT(\dfrac{E[k]}{2}(n+E[k]+2)p+(n-E[l]-2))0.41p & E[k] isOdd \end{cases} \tag{4.33}$$

From the equation (4.32) and (4.33) we can easily calculate the routing overhead for the delay tolerant network in VANET.

4.5.2 Mathematical Analysis of End-to-End delay for DTN in VANETs

In inter-vehicle data transmission within the radio transmission range is assumed to be instantaneous. Hence, the only delay in data transmission occurs when a vehicular node does not have node in front of it within the transmission range. So for data transmission to other vehicular nodes, it may select a vehicle that has less velocity until it is in the transmission range. This type of transmission delays may happen more than once over a stretch roadway. Let us assume the end-to-end transmission delay T_d from a source to a target destination. Let assume for the PDF of the catch-up time T_c, $\int T_c(t)$ is given by following equation.

$$P(X(t)\le x|T_c=t):=P_{X(t)}(x)=P(X(t)\le x) \tag{4.34}$$

From the equation (4.34) we found the PDF of $X(t)$ on conditional to T_c, $\int X(t)|T_c(x_c|t)$. After that multiplying $\int X(t)|T_c(x_c|t)$. by the PDF of $T_c, \int T_c$. We found the combined PDF (Zhang, Mao, & Anderson, 2014). When $t=0$, the two vehicular node must be within the transmission range. Hence the marginal cumulative distribution goes through the following distribution

$$P\left[X_c\le x|X_c\le l\right]=\min\left(\frac{1-e^{-\alpha x}}{1-e^{-\alpha l}},1\right) \tag{4.35}$$

But when $t>0$ the joint CDF can write as

$$F_{X(t),T_c}(x,t) = \begin{cases} F_{X(t)}(x-l) & if \quad x > l \\ 0 & if \quad x \le l \end{cases}$$

(4.36)

For the calculations simplicity we change this function $F_{X(t)}$ in the x coordinates by the transmission range l for the data transmission from one node to another node. The radio propagation is covered the distance l for the distance X_c is the CDF. $F_{X(t)}$ is found by the following equation (4.37)

$$F_{X_c}(x) = \int_{t=0}^{t_{\max}} F_{X(t),T_c}(x,t) f_{T_c}(t)dt \tag{4.37}$$

Where T_{max} is the maximum duration for the distance $x_{\max}(t_{\max} = \frac{x_{\max}}{v_{\min}})$. The combine CDF $F_{X(t),T_c}(x,t)$ can be aliases to $F_{X_1,T_1}(x,t)$ and its PDF to $f_{X_1,T_1}(x,t)$ as they are based on the dependent probability of distance and time. A normal dependent CDF for the total $n+1$ node is

$$F_{X_{n+1},T_{n+1}}(x,t) = (F_{X_n,T_n} * f_{X_1,T_1})(x,t) \tag{4.38}$$

Let's say that x_{max} is the final distance from the source to destination. So from equation (4.37) and (4.38) the delay t can be found by the following function

$G_{t,n}(x) := P[X_n \le x, X_{n+1} > x, T_n \le t] = P[T_n \le t, n+1 \quad vehicles \quad in \quad [0, x_{\max}]]$ as

$$G_{t,n}(x) = \int_{t'=0}^{t} f_{X_n,T_n} {}^*{}_x (1 - F_{X_c})(x,t')dt' \tag{4.39}$$

Here ${}^*x$ is found the one dimensional convolution in x and combine PDF f_{X_n,T_n} is determined from equation (4.38), and f_{X_1,T_1} is found by differentiating equation (4.37) with respect to x and t. $G_{t,n}(x_{\max})$ is define the probability for any time before t such that the data packet has not reached to the final destination. The data pocket reached to final destination is $F_{T_d}(t)$ and found by

$$F_{T_n}(t) := G_{t,n}(x_{\max}) \tag{4.40}$$

From equation the end to end delay is finally found by:

$$F_{T_d}(t) = \sum_{n=0}^{\infty} F_{T_d}(t) \tag{4.41}$$

4.5.3 Mathematical Analysis of Message Propagation for DTN in VANETs

In most cases, the data transmissions of vehicular node in VANETs have a finite life time period. The data packet is discarded after exceed the life time period. In this section we calculate the message propagation probability of DTN. Let us assume that in a VANET with n vehicles are randomly distributed in a region with size $a \times b$ square meter. The radio transmission range of the vehicular node is denoted by l. So the dimension of the network are a and b meter where $a, b \gg l$. Assume a roadway network form by freeway and intersection. The area consists of intersections I = I_1, I_2, ..., I_w , here I_j denotes the j^{th} intersection and w is the total number of intersections that exist in the network. Vehicle i is denoted by veh_i and assume that all vehicles have constant transmission range denoted by l. The total number of vehicular node entering in to the network of road section h_{jk} is consider as a static variable and related stochastic process is model as a Poisson distribution (Ho, Leung, & Polak, 2009). Some experiments show that the result of such a model is very good agreement with real measurements and is also adapted by simulation tools. The probability density function of the network at road h_{jk} is thus given by the next formula

$$P_z^{h_{jk}}(t) = \frac{(a_{jk}t)^z}{z!} c^{-(a_{jk}t)} \tag{4.42}$$

Here a_{jk} represent the mean arrival rate at road h_{jk} and z represents the number of arrivals in the time interval 0 to t. For the calculation simplicity in our analysis we consider a part of the roadway network as shown the figure 4.5.

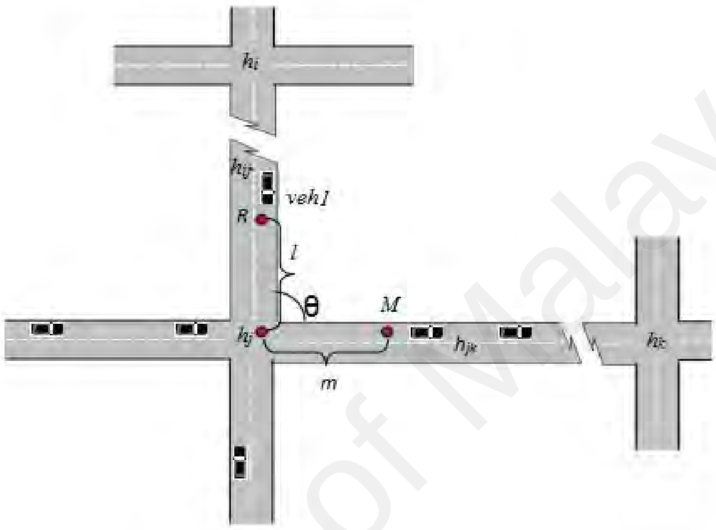

Figure 4.5: An intersection in a road network

Figure 4.5 shows an intersection h_j and roads h_{ij} and h_{jk} consistent intersection h_i with h_j and h_j with h_k correspondingly. The roads h_{ij} and h_{jk} form an angle is denoted by $-$. L is the point of h_{ij} that is l apart from intersection h_j and M the consequent point of road h_{jk}. At the end veh_1 is the head of the information on road h_{ij} and is travelling with speed V_1. Let from starting time $t = 0$ at the point where veh_1 is at a distance less than l from intersection h_j. We are interested in intersections where veh_1 can select any roads from intersection. Otherwise, if h_{jk} was the only choice that is in freeway scenario, the probability of message propagation would be equal to 1 since veh_1 will definitely enter road h_{jk} at their intersection. The first way is by transmitting the information to a vehicle on h_{jk}. We call this probability $p_{h_{ij}h_{jk}}$. The second way is the driving way and we call the probability $p_{h_{ij}h_{jk}}$, where an informed vehicle from h_{ij} turns into h_{jk}. The probability $p_{h_{ij}h_{jk}}$ is strongly related to the traffic and depends on what portion of the arrival rate road h_{ij} has, compared to the total arrival rate of the roads attached to intersection h_j. In this part present a lower bound of the probability to propagate information from an informed vehicle of road h_{ij} to a vehicle in road h_{jk} when these two vehicles are close to the intersection h_j. Here we concentrate on the two basic scenarios to propagate information.

1) By transmitting the information from vehicles on road h_{ij} directly to vehicles on road h_{jk} and

2) By having the veh_1 driving into road h_{jk}

The following equation gives a lower bound of the probability to propagate the information combining the two aforementioned propagation ways:

$$ph_{ij}h_{jk} = p_{tl}^{h_{ij}h_{jk}} + (1 - p_{tl}^{h_{ij}h_{jk}}) * p_{dl}^{h_{ij}h_{jk}} \qquad (4.43)$$

So we need to calculate the probabilities $p_{tl}^{h_{ij}h_{jk}}$ and $p_{dl}^{h_{ij}h_{jk}}$

4.5.3.1 Probability of information propagation among node on intersecting roads ($p_{tl}^{h_{ij}h_{jk}}$)

From the figure 4.5 we say veh_1 containing packet of information on road h_{ij}. Here we need to analysis two different case, in case1, veh_1 was receive information before passing from point R and in case 2 veh_1 has passed from point R without receiving information and before reaching intersection I_j a subsequent node transmit the message to veh_1. For the mathematical analysis, we calculate the probability to transmission the packet form a node following on road h_{ij} to a node passing on road h_{jk} in the time period $[0, y]$, here $y \le \frac{l}{V_{\max}(h_{ij})}$. A higher value for y, even though it will increase the transmission probability, it might be increase the time that a packet needs transmit (C. Song, Liu, Wen, Cao, & Chen, 2011). We denote the first case probability of transmitting is p_t and the second one is probability of receiving p_r

A) Case 1: veh_1 **has the information when it passes from point *R*.**

It was shown that here is the time that veh_1 needs to cover the length l on road h_{ij} and v_1 is the speed of veh_1. Therefore must determined the probability to incoming a node on road h_{jk} at time interval $[0, y]$, since it is certainly going to receive the packet from veh_1. The probability of receiving information can be found by the following equation.

$$p_r = 1 - p_0^{h_{jk}}(y) \tag{4.44}$$

To find the probability of transmission p_t is more complex than p_r. Lets say $d(t)$ is the a closet point from intersection I_j on road h_{jk} , then the radio propagation range of veh_1 can transmit in time t. So any node in I_j to $d(t)$ is going to transmit information. From basic trigonometric rules we may establish a relation between $d(t)$, transmission range l and angle ¯ and V_1 as follows

$$d(t) = (l - V_1 t)\cos\text{¯} + \sqrt{l^2 - (l - V_1 t)^2 \sin^2\text{¯}} \tag{4.45}$$

Considering θ is a right angle then we find $d(t) = \sqrt{l^2 - (l - V_1 t)^2 \sin^2\text{¯}}$. We also assume $X(t)$ is the path from I_j on road h_{jk} that the node neighbouring to I_j has on time, compare to all vehicular node that have entered h_{jk} before $\mathrm{t} = 0$.

$$X(t) = \min(V_i' * (t - T_i)) \qquad i = 1, 2, \cdots . Z(\text{¥}) \tag{4.46}$$

Here V is represent the speed the vehicular node is on the road section h_{ij} . It is consistently distributed in the range $[v_{\min}(h_{jk}), v_{\max}(h_{jk})]$. T_i is the time when node i passed intersection point $I_j (T_i < 0)$, ¥ is the period of time before $t = 0$ when there is a chance the radio propagation range of veh_1 to enter into road h_{jk}. At last Z(¥) is the number of vehicular node on the road section h_{jk} for the duration of period [−¥,0].

The function distribution of the $X(t)$ is determine as follows

$$F_{X(t)}(d(t)) = \sum_{z=0}^{\infty} P[X(t) < d(t) | Z(¥) = z| * P|Z(¥) = z| \tag{4.47}$$

From equation (4.47) we can derive

$$P[X(t) \leq d(t) | Z(¥) = z] = 1 - P[X(t) > d(t) | Z(¥) = z] = 1 - P[V' * (t - T) > d(t)]^Z \tag{4.48}$$

Finally we found the probability of transmitting the message from equation (4.48) as follows

$$p_t = \int_0^y F_{X(t)}(d(t))dt \tag{4.49}$$

B) Case 2. veh_1 passed point *R* without carrying the information and receiving message before arriving at intersection I_j

veh_1 did not get any message when crossing the point R, the message was propagated to the vehicle by a intermediate node before arriving at the intersection I_j. Let us assume $t = 0$ when the node get the packet. Say S is the position of on section of road RI_j on time $t = 0$ and s is the distance that point S has from R. The figure 4.5 shows the notations of case 2. We had to consider the probability that the vehicle veh_2 that travels with speed V_2 following veh_1 will cross the point R by time $t = 0$ at the moment veh_1 may not on h_{ij}. The scenarios have two cases,

i) veh_1 passed point R without having the information and a vehicle veh_2 transmits the information to veh_1 at time $t = 0$. This means that the distance between

veh_1 and veh_2 is smaller than r on time = 0 .

ii) On t = 0, which is the time needed by veh_1 to pass from intersection I_j, veh_2 must not have passed from point R. In order for this to happen V_1 must have been greater than V_2.

For the calculation simplicity we assume that in the scenario of case 2 during the period [0, y] there is at least one informed vehicle in the area RI_j to propagate the information to any vehicle entering road h_{jk}. This means that the the probability of entering is given by the same formula as in case 1.

$$p_r = 1 - P_0^{h_{jk}}(y) \tag{4.50}$$

We have to determine the probability of reception p_r. Now we have $Q(t,s)$ rather than d(t) which is a arbitrary variable based on the time and the initial value of t, as s is uniformly distributed along RI_j.

$$Q(t,s) = (r - s - V_1 t)\cos^{-} + \sqrt{l^2 - (l - s - V_1 t)^2 \sin^{2-}} \tag{4.51}$$

When $^{-}$ is right angle the $Q(t,s) = \sqrt{l^2 - (l - s - V_1 t)^2 \sin^{2-}}$. The function distribution that we are interested are determine by $F_{Q(t,s)-X(t)}(0)$ .So,

$$F_{Q(t,s)-X(t)}(0) = \int_0^l \sum_{z=0}^{\infty} P[Q(t,s) - X(t) < 0 | Z(\text{¥}) = z] * P[Z(\text{¥}) = z] * f_s(s)ds \tag{4.52}$$

We can conclude from case 1 if during period [0,y]. Q(t,s) is greater than X(t), the probability of receiving is

$$p_t = \int_0^y F_{Q(t,s)-X(t)}(0)dt \tag{4.53}$$

So, we find both the receiving and transmitting probability, to determine the overall probability $p_{tr}^{h_{ij}\,h_{jk}}$ to find the transmission efficiency from road h_{ij} to h_{jk}. Therefore, the probability for each case need to be found separately. We denote ^{2} the time gap between the vehicular node veh_1 and veh_2 and if the velocity difference of the two vehicle is V then the distance is $\text{²}V$. From the equation (4.53) time gaps between two vehicles are distributed according to the following PDF

$$p_{\text{²}}(\text{²}) = \text{ª}e^{-\text{ª²}} \text{ and } P_{\text{²}}(\text{²} > T) = e^{-\text{ª}T} \qquad (4.54)$$

So from the equation (4.54) we find the probability for this case is

$$P_1 = P_{\text{²}}(\text{²} > \frac{l}{V}) = e^{-\text{ª}\frac{l}{V}} \qquad (4.55)$$

And case 2 is the complements of case 1

$$P_2 = 1 - P_1$$

Therefore, the overall probability of transit a packet from road h_{ij} to h_{jk} during a time period y is

$$p_{tr}^{h_{ij}h_{jk}} = P_1 * (p_t^1 + (1 - p_t^1) * p_r^1 + P_2 * (p_r^2 + (1 - p_r^2) * p_t^2 \qquad (4.56)$$

4.5.4 Mathematical Analysis of Message Propagation on Highway for VDTN

The message propagation probability should be used to support the decision if a packet has reached to its destination. The probability of a packet reach to its destination from a veh_1 to veh_2 on a road segment is

$$P_{(1,2)} = P'_{1,2} + (1 - P'_{1,2}) \times p \qquad (4.57)$$

Where $P_{(1,2)}$ is the delivery predictability of a vehicular node veh_1 and p ∈ [0,1] is an initialization constant. Which will confirm that the vehicular node often encountered have a maximum delivery predictability. If a source and destination node comes across each other they are likely to be good transmission pair and they poses a very high delivery probability. From the equation (4.54) we found the delivery probability as follows

$$P_{(1,2)} = P'_{1,2} \times \yen^{2} \qquad (4.58)$$

The message propagation probability has transitive characteristics. Finally we can write the probability of a packet reach to its destination from veh_1 to veh_2 on a road segment as

$$P_{(1,2)} = P_1(P'_{1,2} + (1 - P'_{1,2})\yen^{2}) \times P_2(P'_{2,1} + (1 - P'_{2,1})\yen^{2}) \qquad (4.59)$$

4.6 NS-2 Based Analysis

Deploying and testing VANETs involves a high cost and intensive labour. Hence, simulation is a useful alternative prior to the actual implementation. VANET simulation is fundamentally different from MANET simulation because, in VANETs, the vehicular environment imposes new issues and requirements, such as constrained road topology, multi-path fading and roadside obstacles, traffic flow models, trip models, varying vehicular speed and mobility, traffic lights, traffic congestion, and drivers' behaviour. The performance of the proposed AGDR routing protocol is analyzed considering the metric, the ratio of delivered packet, generated overhead and average time delay. The network simulator plays a vital role to examine the performance of the proposed routing protocol under realistic vehicular environments. In this simulation Network Simulator-2 (NS-2) is used for the network simulations and SUMO is used to generate the vehicular traffic for simulations. To test the performance of adaptive delay tolerant routing in vehicular environment extensive simulation is required. Next chapter 5 discuss details about the proposed adaptive geographic delay tolerant routing protocol.

4.7 Conclusion

In this chapter, after reminding the main goal of this thesis, the methodology for solving the problems and achieving the objectives were explained. A detail framework was presented for the adaptive delay tolerant routing in vehicular environment. It shows that the node density depicts the network connectivity in a sparse network, so we can take necessary steps to prevent the network failure when the density of vehicle is low. The relationship between the density of vehicle and the network connectivity was discussed. After that mathematically analysis the performance metric; the main aim of the research is to propose an adaptive geographic routing algorithm for vehicular network which acts in low density as DTN. It is based on the parameter, vehicle positions, route them and most important to their behaviour of above parameter. Solution to implement a delay tolerant protocol is the best in VANET, when there no direct connections between source to destination. The AGDR protocol operates in two modes; first mode is developed for the intersection scenario and the second mode for the freeway. The idea of this protocol exploits the knowledge of the DIL information with the aid of an equipped GPS, navigation system and vehicle's Direction Indicator Light. Each vehicle can obtain knowledge about the next road direction the vehicle is intending to follow.

CHAPTER 5: ADAPTIVE GEOGRAPHIC DELAY TOLERANT ROUTING IN VANETS

5.1 Introduction

In VANET, the V2I communication type is practically unavailable as it is very expensive to install the infrastructure that covers the road network when compared with the V2V communication type. The probability of changing the interconnection between vehicular nodes can be significant due to the high mobility of vehicle. Hence finding and maintaining a stable and robust router from the source to a destination mode is very important. The basic requirements of a routing protocol design to avoid packet drops and to confirm that the next-hop node has a stable data delivery route by using minimum cost for control packet. The high mobility of vehicular node increases the rate of route failure in vehicular networks. This will generates congestion problems due to traffic backlog and consume huge bandwidth. Therefore to achieve adaptive geographic delay tolerant routing efficient and responsive the main objective is to minimize the effect of mobility by increasing the stability and packet delivery probability. In the proposed AGDR protocol select the intermediate nodes to forward data packets from source to destination node is based on the specific vehicular dynamic parameters. The aim of the proposed routing protocol focuses on the process of delivering messages between vehicles from the source to its destination using a novel technique AGDR. In order to promise successful packet delivery to its destination; developing an efficient routing mechanism is the main challenge that needs to be tackled; this is the main goal of this work.

This chapter propose new Adaptive Geographic DTN Routing (AGDR) protocol aims to initiate a robust and long live route from source to the destination reducing the flooding and the rate of link breakage in the established path. The AGDR operates in two modes. The details of these two modes are presented and explained.

5.2 Challenges with DTN Protocols in VANET

The development and deployment of DTN have been highly motivated by their intended real life scenario in VANETs. Due to the limited transmission range of an RSU, remote vehicles in DTN, have to rely on intermediate vehicles to relay the packets. During the message relay process, complete end-to-end paths may not exist in highly partitioned VANETs. Therefore, the intermediate vehicles must buffer and forward messages opportunistically (Benamar, et al., 2014). Through buffer, carry-and-forward, the message can be delivered to the destination even if an end-to-end connection does not exists between source and destination. The main objective of routing protocols in DTN is to maximize the probability of delivery to the destination while minimizing the end-to-end delay. Also, vehicular traffic models are important for DTN routing in vehicle networks because the performance of DTN routing protocols is closely related to population and mobility models of the network. The messages should be routed toward the destination node to overcome the fragmentation problem of the ad hoc network. DTN routing is a kind of geographic routing. The neighbour detection in geographic routing use periodic beacon message. The beacon message has both a positive and a negative effect. The positive effect, whenever a message is transmitted by a node, it will be received by all the nodes within the broadcasting range of the sender. The negative effect results from possible interference with other communications. In short beaconing disseminates messages to all the nodes in the network but may also trigger a broadcast storm that can overload the network. A broadcast storm can be avoided through controlled beaconing schemes that reduce the number of retransmitting nodes. This will reduce network traffic while ensuring that the intended nodes receive the message.

Three main challenges have been identified in developing routing protocols for VDTN. The first challenge is to determine the location of the destination node. The second challenge is to develop an efficient forwarding strategy that minimizes the possibility of overloading problem. The third challenge is to develop a robust recovery strategy in case the route to the destination node is not readily available using the carry-forward mechanism.

5.2.1 Destination Discovery

To establish communication between two nodes in a VANET will require the knowledge of the location for the destination node. The transmitting or initiator node must know the destination geographic position, vector and future direction so that the packet can be directed toward it. Most routing protocols for ad hoc networks assumed the availability of the location server or service. This assumption limits the applicability of VANETs by depending on infrastructure. The protocol should be equipped to find out the destination on its own without reliance on any location service. When a source attempts to find a destination with an unknown position, it must explore the whole network in order to locate the destination. Conventional ad hoc routing protocols are inclined to combine destination discovery with optimal route discovery. As a result, every node in the network is involved in rebroadcasting the routing request messages. Discovering the destination location should not cause excessive overhead network traffic and should obtain the location from the network. A location service is used to acquire the location of the destination node. The vehicular nodes in a DTN register with the location service and update it adaptively with their position, vector and Direction Indicator Light (DIL) information. When a node wants to send a message to a particular vehicle it contacts the locator service to request the destination node location. Designated servers with well-known addresses are used in classical RSU networks to serve as position servers. In the case of VANET that have no fixed infrastructure, it would be difficult to obtain this information if the server itself were a part of the network. A decentralized approach to location services has been investigated, as reported by Jerbi et al. (Jerbi, Senouci, Rasheed, & Ghamri-Doudane, 2009). For VANET routing protocols, the nodes in the network should be able to locate their intended destination efficiently by using the provisions in the protocol and not by depending on any infrastructure based location servers.

The destination of the message is dependent on the type of message being transmitted. If the message of a HELLO beacon is being transmitted, the destination is limited to the nearby neighbours. The originating node for this kind of packet sets the packet type to HELLO beacon and broadcasts the packet. The nodes within a one-hop vicinity of the sender receive the hello packet and update the corresponding neighbour entry in their list. The destination location can be established either by using a hop counter to limit the broadcast range or by using a source location based radial distance. If the destination location is unknown, the protocol must locate the intended destination using adaptive throughout the network. An adaptive HELLO beacon is used to avoid excessive network traffic. Each node that receives the query message evaluates its own position, vector and DIL information in order to determine its contribution to the overall process of determining the destination location. This step means that the intermediate nodes wait and allow the nodes on the farthest side of the sender node to propagate the message more effectively. Once the destination location is discovered, the routing strategy makes use of this information to limit the flow of messages to the intended physical location, thus effectively controlling the overall network traffic. The main component of any routing protocol is its packet forwarding strategy. The forwarding strategy for DTN must be based on the fact that the vehicle position, vector and DIL information is constantly changing. Each time a packet is received at a node that has not yet reached the destination it goes through a process of evaluation to assess the contribution of the node towards the intended destination. Prior to transmission each node transmission evaluates its contribution to the dissemination of the message and then decides whether to retransmit or discard the packet. AGDR uses a similar idea but model the retransmission time in a more comprehensive manner that suitable for location based routing protocols.

5.2.2 Packet Forwarding Strategy

The nodes in an ad hoc network communicate with one another by sending and receiving data packets. In wired networks, this operation is very simple because the nodes have fixed IP addresses and the routing protocol relies heavily on routing tables to forward packets to nodes that are located in the direction of the right destination nodes. In VANETs, routing tables are not feasible because constant changes in network topology very frequently render them as being outdated. The cost of updating routing table's network wide is significantly high in terms of bandwidth utilization. Therefore, a different method of packet forwarding must be adopted. In the absence of routing tables, the forwarding strategy is guided by the geographic position, vector and DIL information of the destination node. The intermediary nodes are responsible for forwarding the packet toward the destination node. In a geographic routing protocol, a forwarding strategy controls the overall broadcast traffic in the VANET.

5.2.3 Recovery Mechanism

In the DTN, communication routes between nodes may not always be maintained due to rapid changes in the topology. An effective built-in recovery strategy is therefore required so that communication can be maintained. A recovery strategy should be an inherent part of the protocol because fragmentation may be a significant problem when nodes are vehicle. An effective recovery strategy limits network traffic and provides better packet delivery in the network. A recovery strategy is needed when the forwarding strategy fails to deliver the packet to the intended destination. In this case, rather than dropping the transient packet, a recovery strategy can be employed to the

DTN and the carry-and-forward of the packet until such a time when new neighbours are detected.

5.3 Proposed Adaptive Geographic DTN Routing (AGDR) Protocol

An adaptive geographic routing algorithm for low density network is proposed which acts as the DTN in VANETs. It is based on the parameter of vehicle positions, direction, speed and predicted future direction. Solution to implement a delay tolerant protocol is the best for VANET where most times there are no direct connections between source nodes and destination nodes. The AGDR protocol operates in two modes; first mode is for the intersection in the urban area and the second mode is for the freeway scenario(Nasir, Ali Shah, Qureshi, Oche, & Noor, 2014). The idea of this protocol is represented by exploiting the knowledge of the DIL information. It collects all the information with the aid of an equipped navigation system and vehicle's DIL information. Each vehicle can obtain knowledge about the next road direction the vehicle intend to follow. Direction Indicator lights (DIL) are amber in colour and can be located at the front, the rear and sometimes at the side of the car on both the left and right hand sides. One use indicators to show an intended change of direction, whether turning left or right or moving out into traffic. Indicator should be used in good time, giving other road users chance to react and adapt to your signal. In AGDR the DIL is one piece of information that needs to be shared between the nodes in the network. This information can be stored in the buffer of each received node.

In the first mode, AGDR is developed to manage intersection scenarios. In this mode the DIL information for each node is considered in the process of selecting the next hop node. However in this mode the forwarding node will divide its neighbouring nodes into four groups based on their DIL information. Then, the DIL value will be determined from the vehicular direction indicator light which represent predicated future direction.

If more than one node is found in each direction then selects on node from each group to act as an intermediate node to propagate the message in that direction rather than broadcasting the message to all the vehicular nodes.

The second mode of AGDR is for the freeway environment; this mode the DIL information has three values; "0" means the vehicle will travels in the same direction of the freeway and will not leave the freeway in the next exits; while "01" or "10" represent the vehicular node wish to exist from the freeway. Considering the DIL information for selecting the next hop node will increase the network stability by decreasing the link breakage in a partially connected network. Normally the nodes in VANETs try to maintain connectivity and transfer the data packet to its final destination. All the intermediate nodes are responsible for transmit and receive the message from one node to another node in the network. A next-hop selection algorithm takes the responsibility which node is select the intermediate node based on the parameter of neighbour node current direction vector and DIL information. The method guarantee to transmit data packets to same direction of desire destination. So the procedure can avoid the broadcast the data message in all direction and make a positive impact on network performance by decreasing the generated packet overhead. Hence, finding and maintaining robust and stable routes from source to the destination for routing protocol in vehicular delay tolerant environment is the most important. A routing protocol has to fulfil the basic requirement that it avoid packet drops, maintain the source to destination path until the message successfully delivered with a minimum packet overhead.

5.4 Adaptive HELLO Beacon message

AGDR uses periodic HELLO beacon messages for information sharing that, contains position, vector and DIL information. In this procedure, a vehicular node wants to transmit a data packet will broadcast a HELLO beacon message with some specific information to notify the neighbour vehicle. The neighbour vehicle also response by sending their up-to-date information by another HELLO beacon message. If any vehicular node wish to leave the network in the next exist it also declare to the neighbour vehicle to request not transmit unnecessary packet. Conversely, if any new vehicle inter into the network it also broadcast a HELLO beacon message to the nodes of the network. The details of adaptive HELLO beacon procedure represent in the pseudo code. Table-5.1 shows the HELLO message format. The idea is to implement forwarding logic into forwarding vehicle (which holds the packet) to select the next-hop vehicle as a relay according to information acquired through DIL.

Table 5.1: HELLO message format for AGDR

Field	Value
Node_IP	Node IP Address
Node_Dir	Node Current Direction
Node_DIL_info	Predicted Direction Information from DIL
Node_Pos	Node Current Position
Node_Vel	Node Moving Velocity
Node_info	Information about the neighbours nodes

If the next-hop vehicle has DIL information equal to “1” the vehicle will retain the packet. In this situation, the forwarding vehicle will ignore this vehicle and look for an alternative vehicle that has DIL information equal to “0” or “-1”. In other words, the forwarding vehicle will select the next-hop vehicle that continues in the same road without making any diversion in its route. Thus the probability of delivering messages to a specific destination increases; producing a stable link selection. This protocol imitates a delay tolerant behaviour by using carry-and-forward strategy. When there is no available vehicular nodes to act as an intermediate node for transfer the data packet from source to the final destination create a communication gap. The node containing the packet retains the packet until found a new node upon find a new node for relay the packet to that node. A disconnection at a relay is defined by lack of vehicles in the direction of the destination. Recovering from a disconnected link using vehicle's current position and the destination of the packet is not sufficient. Therefore, DIL information is vital when deciding the next hop vehicle. Suppose a forwarding vehicle needs to forward the packet to the next-hop vehicle within the range and direction towards the destination region. Without the DIL information of the next hop, a suboptimal relay might be selected for the packet. In other words, DIL information can be used effectively to predict the optimal relay which can be defined by the values as shown in Table-5.2.

PSEUDO Code for the Adaptive HELLO Beacon Message

Notation

S is the source Node

D is the destination node

L is the leaving node from the highway

M is the new vehicle interring into highway

N_i is the any node

if S want to Transmit

  if neighbour N_i is cache

  THEN

    Start to transmit

  else

   Broadcast HELLO beacon for discovering the neighbour

else if (N_i=L)

Then broadcast HELLO Message to remove from neighbour list

else if (N_i=M)

Then broadcast HELLO beacon message to update neighbour list

else

if N_i change speed (press brake or accelerator)

Send HELLO message

end

5.5 Description of AGDR Protocol

The proposed protocol is designed to use a message forwarding mechanism based on the geographic location of the destination node. The message is propagated in the direction of the destination node using any available intermediate nodes. If more than one node is capable of forwarding the message in its intended direction, then the only node that forwards the message is the one that is able to make the best contribution in terms of delivering the message to its intended destination (Vaqar & Basir, 2007). The AGDR routing protocol is designed to meet the following criteria:

i) Minimize the use of flooding by selecting appropriate nodes to which it will forward the packets.
ii) Avoid generating extra control traffic.
iii) Make use of the geographic position, vector and DIL information about destination nodes whenever possible.
iv) If there is link failure, use recovery mechanism by carry-and-forward technique.

The proposed protocol is based on the performance related to the type of message it forwards. It recognizes message types and routes packets according to the state of its knowledge about the location of the destination node. When a direct route is unavailable the protocol enters into recovery mode and tries to route the packets after a specified time delay. The following subsections present the constituent components of the proposed protocol in detail. The next section describes elaborately the forwarding strategy for intersection and freeway section.

5.5.1 Intersection Mode

In AGDR intersection mode, each node in the network classifies its neighbouring nodes into four different direction groups (G_1, G_2, G_3 and G_4) according to their DIL information as shown in figure 5.1in next page. The AGDR protocol demands each mobile vehicle in VANET to send its mobility information to neighbouring vehicles periodically. According to the knowledge obtained from the HELLO beacon message, the mobile vehicle in the network is able to group its neighbouring nodes into four directional groups according to their DIL information.

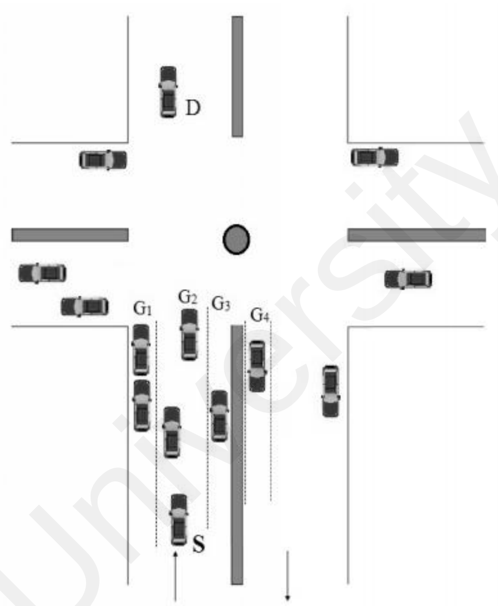

Table 5.2: DIL Information for intersection

Code	Indication	Group
00	No signal/Highway	G_2
01	Right Turn	G_3
10	Left Turn	G_1
11	Reverse Direction	G_4

Figure 5.1: The node distribution based on the DIL.

Each group will represent the direction of vehicles as described by a specific predicated direction, from DIL information as shown in Table 5.2 in next page. If a source node wants to send a packet to a destination node, the source node acquires all the knowledge about itself. In addition to this, the source node acquires sufficient knowledge relating to position, velocity, current direction and predicted direction from the DIL information and the group number of neighbouring nodes from periodic beacon.

5.5.1.1 Packet Sending Process

AGDR performs with some preset assumption that the type of the network is a delay tolerant. A disconnected area can be generated any time when no vehicles are available in a specific area. Each vehicular node in the network has adequate knowledge about its position and vector information and predetermined route for its journey, as utilized by the GPS and navigation system when a source node has a packet that needs to be sent. Figure 5.2 shows the flowchart of the packet sending process.

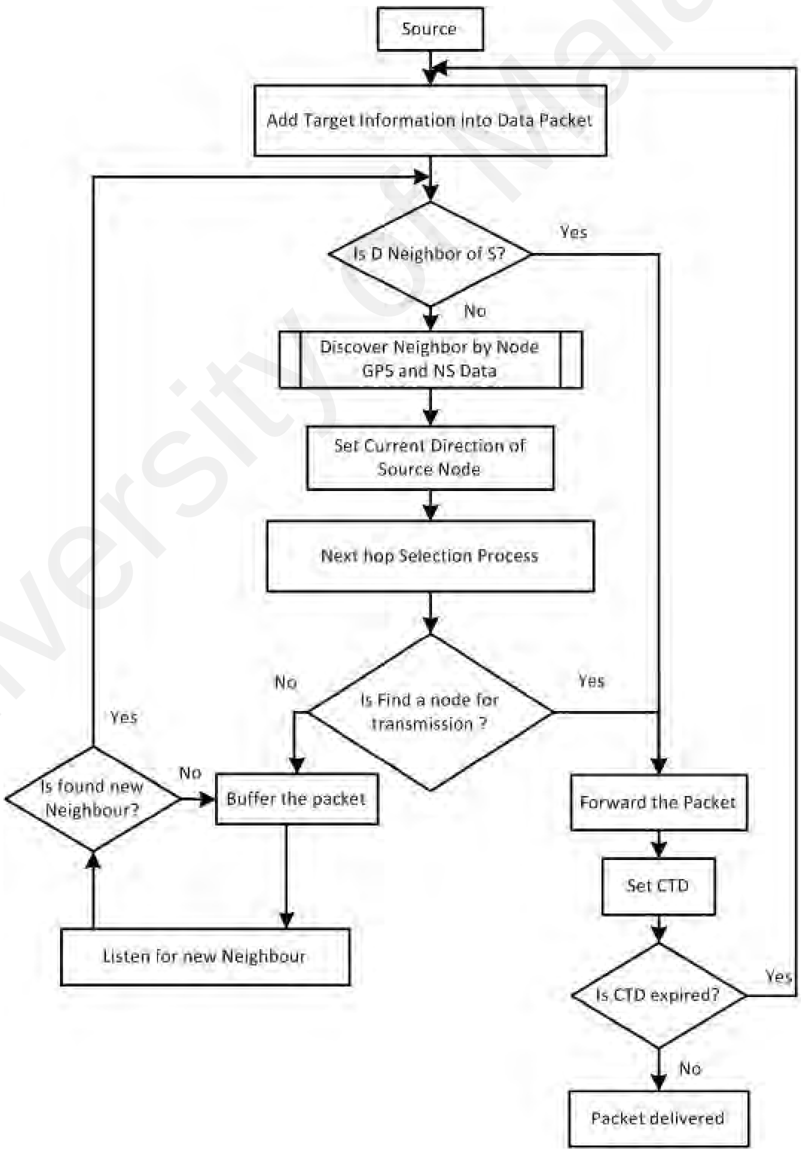

Figure 5.2: Flowchart of the AGDR routing protocol

When a source vehicular node needs to transmit a packet to destination node D, the source node initially finds the location of the destination to its own cache. If it has found the destination node address to its own neighbours table then source node just forward the message to the destination. If the destination node address not in the source neighbour table, then the source node will try to find the forwarding node called a relay that is close to the destination node according to the next hop selection process. The next hop selection process of selecting an appropriate relay node based on information of position, vector information, predicted future direction through the DIL information and speed. The details of the next hop selection process are illustrated in Figure 5.3, where it gives a result that is true or false. The result for being true comes when a relay node is found and if otherwise, is consider to be false. If no node is found for delivering the packet then the source node will hold the packet in its own buffer and continue searching for new neighbour's candidates for receiving the packet. The source node will deliver the packet to the destination if a new relay node is found. This procedure is called the carry-and-forward.

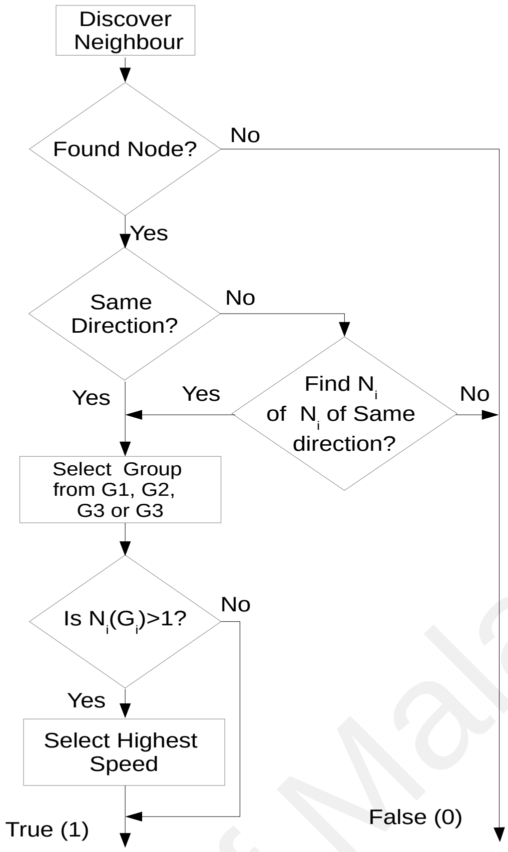

Figure 5.3: Next hop selection process for selecting the relay in intersection

i) Figure 5.3, shows that if a neighbouring node found a node that is closer to the destination S, then S will check for the current direction of this node.

ii) If the neighbour going to the same current direction with the node S then it checks that is there any intersection at in front by the digital road map if there is intersection ahead, then check DIL information.

iii) If a neighbour with appropriate DIL information is found by the S node in its cache, the S node forwards the packet to this node. If more than one node has appropriate DIL information, then the S node will select a node from each of the four groups. In instances where more than one appropriate node is available in each group, the node with the highest speed will be chosen.

iv) If no neighbour node with appropriate DIL information is found in its cache, node S will look for neighbours of neighbours that have same direction information. If more than one neighbour is found, the node with the highest speed will be chosen, as it is faster towards the destination; otherwise it will retain the packet.

v) If no neighbour is found in the same current direction, the opposite direction is look who have neighbour of same direction of the destination node.

vi) If an appropriate node is found, then S will cheek for its DIL information, if more than one appropriate node are found it will select one from each group with the highest speed.

vii) If there is no neighbour then source node will buffer the packet until a new node appears in its neighbour list.

5.5.1.2 Packet Delivery Confirmation

When the forwarding vehicle intends to forward the packet to another intermediate vehicle, it is important to send back an acknowledgment to the sending process. For this reason we set a Confirmation Time Duration (CTD) when sending node transmits a message. When the forwarding vehicle wants to send the packet, it sets the CTD to a specified threshold value, and the value of this counter will be decremented. If the confirmation is received before the CTD has elapsed then the CTD stops. Otherwise, if the time is elapsed and no confirmation message has arrived, the packet is dropped or discarded. Therefore the sender vehicle looks for an alternative vehicle and resends the packet.

5.5.1.3 Example of packet propagation process in AGDR

As shown in figure 5.4 the node intending to forward the packet to the node destination is willing to classify its neighbour nodes according to its DIL information. In this section the algorithm of AGDR has been illustrated in the following example. The sender node S wants to transmit a packet in all directions after finding an intersection ahead. Node S wants to select the forwarding node known as relay based on the position of each vehicle; closest node to the destination than node S. Node I_1, I_2 and I_3 have been elected as the suitable nodes to hold the packet towards the destinations. The suitable node is defined as those nodes delivered the packet toward destination faster than other nodes and they are closer to the destination and less chance to packet drop. Figure 5.5 show that the sender node S will forward the packet to the left by selecting node I_1 and I_2. For the right side the sender node will select the node I_4 as it has neighbour I_3 want to transmit it in the right direction. When the density of vehicle is very low there is less probability to find a in the same current direction, then the node in the opposite direction which has a neighbour with same direction is selected for intermediate node.

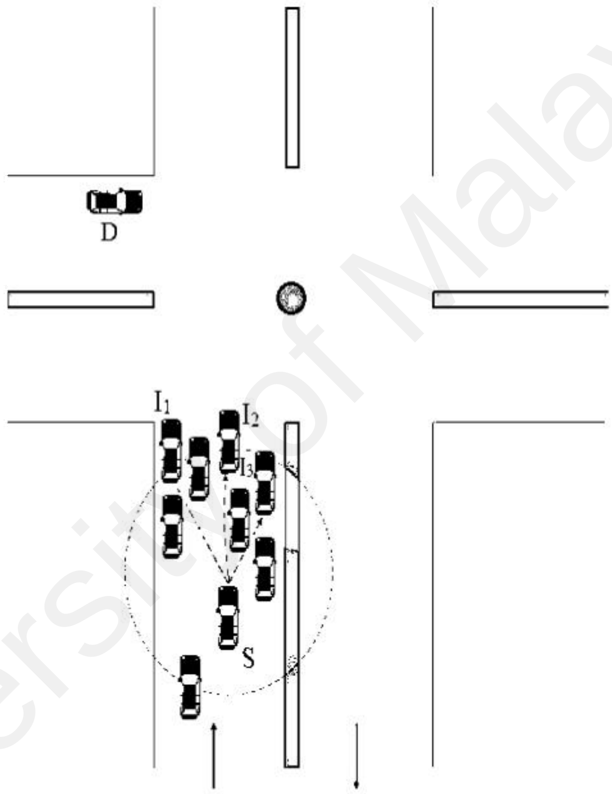

Figure 5.4: Selection of Relay based on position

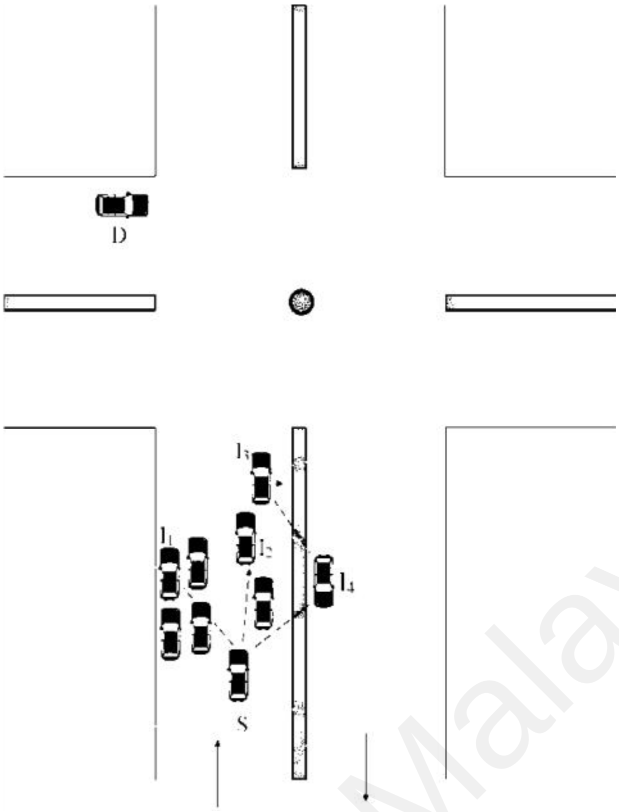

Figure 5.5: Selection of Relay based on DIL information

5.5.2 Freeway Mode

In the intersection mode the vehicle chose a next hop from any of the group but in the freeway mode the grouping is quite different. Therefore AGDR for intersection is not suitable for the freeway. The idea is to implement forwarding logic to select the forwarding node (relay) according to information acquired through DIL. If it has a DIL information leading the vehicle to another route before it reached its destination; the DIL information will have the values according to Table 5.3.

Table 5.3: DIL Information for freeway

Code	Indication	Generated Signal
00	No signal/Highway	0 (Stay in the same road)
01	Right Turn	1 (Enter into or exit from the road)
10	Left Turn	
11	Not use	-1 (Opposite Direction)

This section describes the process of sending the packet from the source and intermediate node, and also the process of sending packet delivery confirmation.

5.5.2.1 Packet sending process

For the freeway mode it uses separate next hop selection process. It also gives feedback true and false like for the intersection.

5.5.2.2 Next hop selection process for selecting the next hop node

This section describes the next-hop selection criteria. In order to increase the packet delivery ratio and system stability, a next hop selection process is designed.

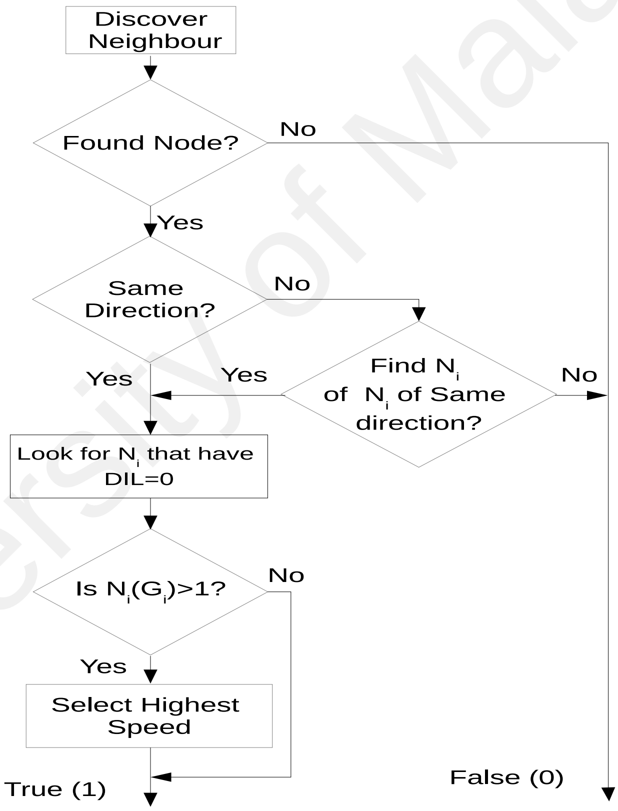

Figure 5.6: Flowchart of Next hop selection Process for the freeway mode

Figure 5.6 shows the destination node D is not in the source node cache, and then the source node S starts the next hop selection process to find out a suitable next-hop node. S looks for a neighbour that is closer destination to D than itself by using the next hop selection process. The source node S want to transmit packet to the destination node D then the node S check its cache if found the D then forward the packet otherwise it send a HELLO message. The forwarding node checks if any of the nodes have a current direction onward the packet destination. If such node found then it will check its DIL information. For more than one node select the highest speed one. If no node is found with same current direction then look for an opposite current direction which have a neighbour of same current direction and forward the packet. When there is no node found, then data packet is buffered and repeats the whole process.

5.5.2.3 Example of packet propagation

The following example described how a sender S transmits a packet to the destination using AGDR protocol. S is the vehicular node S travelling on the freeway. It wants to transmit data to a specific destination so a multi-hop process is used as shown in Figure 5.7. The source node S selects an intermediate node that is closer to the destination than itself which means it obviously never select the vehicle likes I_0 or I_3, because its position is not satisfying the condition of the first selection criteria of next hop selection process.

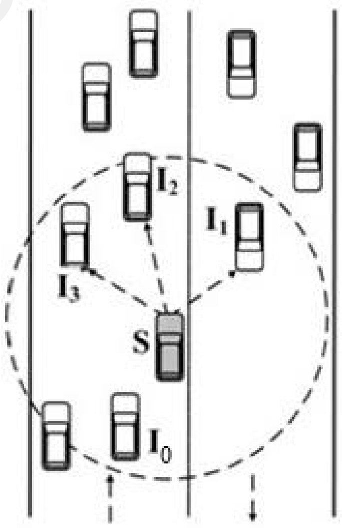

Figure.5.7: Next hope selection based on position

After that, S checks if the selected vehicles have an appropriate current direction, as shown in Figure 5.8. The vehicle will exclude vehicle I_1 in case another vehicle with the same current direction is available such as vehicles I_2 and I_3. The source then checks for the DIL information on selected vehicles such as (I_2 and I_3). The vehicle with the DIL information equal to '0' is selected, which means that the vehicle will not divert its direction in the next exit. It is evident from the illustration that if S fails in finding a relay having less distance towards the destination with current the direction having value 0, then S checks for other neighbours with a current direction equal to "-1" which specifies second lane with opposite direction. Figure 5.9 show how the next hope selection based on the opposite direction. The packet delivery confirmation sends back an acknowledgment to the sending process and work as same procedure like intersection mode.

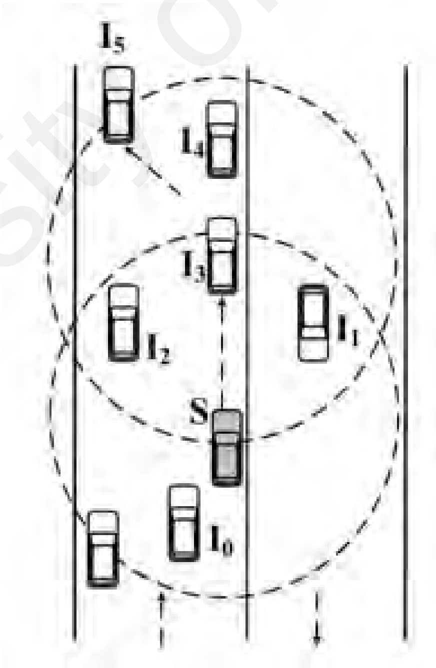

Figure 5.8: Next hope selection based on direction

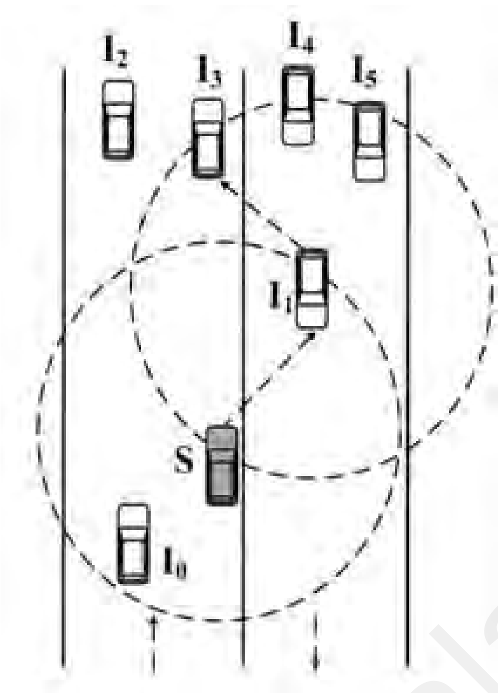

Figure 5.9: Next hope selection based on opposite direction

5.5.3 Mobility knowledge Acquisitions

In AGDR, each vehicle sends position and vector information to its neighbours. Therefore, each vehicle in the network acquires sufficient information regarding the local topology and the neighbours of the 1-hop neighbours for next hop selection. Periodic transmission of messages occupies the network sources but it serves as a trade-off between accurate relay prediction and network saturation in a self-organizing vehicular network. The acquired mobility information serves as an input to the packet sending process for relay selection and forwarding.

5.5.4 The Location Information

This thesis proposes location detection for the VANET. The model assumes that the entire node knows its own geographic position by the use of the GPS. ‘Furthermore, it considers that vehicles are equipped with digital maps to acquire more consciousness about the road topology and the paths along which they are travelling (Brahmi, Boussedjra, Mouzna, Cornelio, & Manohara, 2010). A vehicle S wants to send a packet to another vehicle D, it first checks if the vehicle D is within its neighbourhood, if yes it will forward the packet directly to the destination vehicle D. If vehicle D is not within the neighbourhood of S, then S gets the location information of D and forwards the packet to D with the help of other vehicles moving in the direction of D if there is dense traffic and D is not far away apart. If D is far away apart and traffic is sparse then apply the AGDR protocol.

5.6 Conclusion

In this chapter we described details about the proposed AGDR protocol. The flowchart has shown the flow of protocol. In the adaptive HELLO beacon message procedure, it has shown how to reduce the control packet overhead. A packet sending process with intermediate node selection both for intersection and freeway is presented. To analyze the performance of an AGDR protocol, determine the number of delivered packet, average time delay and the generated overhead traffic obtained from applying the DIL information is necessary. An appropriate network simulator is necessary to examine the performance of the proposed routing protocol and study how the network would behave under different conditions. Compared to the cost and time involved in setting up an entire test-bed containing multiple networked computers, routers and data links, network simulators are relatively fast and inexpensive. Hence, they allow researchers to test scenarios that might be particularly difficult or expensive to emulate using real hardware, especially in VANETs. Network simulators are particularly useful. The network simulator is determined the simulated environment and metrics explaining the parameters of proposed AGDR protocol. The next chapter covers details about simulation setup, experiments and result analysis.

CHAPTER 6: SIMULATION AND RESULTS

6.1 Introduction

To validate the developed protocol, a comprehensive simulation environment was designed and implemented. Due to the unique characteristics of VANET such as lack of central coordination, dynamic topology, shared radio channel, limited resource availability, hidden terminal problem and insecure medium, experimentation and performance analyze of the developed framework can be achieved via simulation tools. The construction of real test-beds for any vehicular networks' scenario is an expensive or in some cases impossible task if metrics such as testing area, mobility and number of vehicles are taken into account. Besides, the experiments are not repeatable and incur high cost and efforts. This chapter presents the experimental setup used to simulate and analysis the performance of the AGDR protocol. The performance of the AGDR needs to be tested, to show its effectiveness in compare to other routing protocols in VANET, and therefore simulation tools needs to be used for this purpose. Various simulation tools have been utilised to simulate and examine the performance of routing protocols in VANETs. Among those tools are for example the NS-2 (Fall & Varadhan, 2007), GloMoSim (Gerla, Bajaj, Takai, Ahuja, & Bagrodia, 1999) and OPNET Modeller (Modeler, 2009) , either C++ or the Java programming language are used to build the simulators.

6.2 NS-2 Based Analysis

The proposed AGDR protocol is simulated using the NS-2 for the purpose of analysis, examining and comparing it with some other routing protocol in the same domain. The motivation behind selecting the NS-2 as the simulator for this work is that it provides a range of characteristics that make it an eminent simulator tool. It is a discrete event simulator targeted at networking research and provides extensive support for simulation of routing, multicast protocols and IP protocols over wired, wireless and satellite networks. It has many advantages that make it a useful tool, such as support for multiple protocols and the capacity of graphically detailing network traffic. NS-2 is available on a number of platforms such as FreeBSD, Linux, SunOS and Solaris. NS-2 also builds and runs under Windows with Cygwin. According to the objectives of this research, the main emphasis of this study depends on the analysis and examining of VANET routing protocols. These protocols are needed to be defined individually within their specified Tool Command Language (TCL) file along with their supporting components. The movement and traffic files are generated and compiled independently before associating with NS-2 simulation, which would then be in the receiving format for NS-2 to combine with the body of actual TCL. Initializing the routing protocol within a TCL file as inputs in relationship of particular traffic and movement files, the NS-2 simulates accordingly. Ultimately, as a result, it produce two files i.e. Network Animator File (*.nam) and a Trace files (*.tr) as the outputs. The NAM file consists of all the procedure to be performed at the time of simulation with all the positioning and graphical information and their declared parameters. This NAM file then can be called or executed by its built-in “nam” command from the process component of NS itself. The entire simulation and analysis workflow shown in Table 6.1 can be divided into three different phases:

Table 6.1: Workflow of Simulation

Phase-I	1. Take region of interest by open street map (OSM) 2. Preparing “.xml” file for mobility model generator by SUMO 3. Mobility Model trace file generation
Phase-II	1. Installation of NS-2 (NS-allinone-2.34) on Linux Fedora Platform 2. Generating / editing ‘OTcl’ file for simulation

	3. Using cbrgen.tcl file to include in primary '.tcl' file 4. Running simulation 5. Generating NS2 trace file and NAM
Phase-III	**1.** Analysing trace file to evaluate performance

6.2.1 Phase-I: SUMO and Mobility Model

SUMO stands for Simulation of Urban Mobility. SUMO is a microscopic road traffic simulation which helps the VANET research community for the complete traffic simulation. SUMO has a great interest in the analysis of V2V and V2I communication. SUMO has a direct coupling between NS-2 and TraNS. A few remarkable feature of SUMO are complete workflow (network and routes import, DUA, simulation), many network formats (VISUM, Vissim, Shapefiles, OSM, Tiger, RoboCup, XML-Descriptions) may be imported, high interoperability through usage of XML-data only. The road map is the combination of connection of roads, streets and highways. In SUMO two nodes (junction) form a street and edge is the street between these two nodes. Each street or road has its own property and rules. There are four different file types, namely node, link, link property and lane connection/traffic movement files for designing and implementing any road map in SUMO. The first and second files include the information about the junctions (nodes) and the streets (links) between them. Node and link files are saved and named with extensions .nod.xml and .edg.xml, respectively. The two other files with extensions .con.xml and .typ.xml are required to specify allowed traffic movements, lane connections at intersections and link types. We have to determine the required number of nodes and the links between them. It means that road map should be converted into a graph with nodes and edges and the following files should be created.

i) Node file: Nodes correspond to junctions on the road map with specific and predefined id and coordination. These coordinates are specified by two-dimensional numeric values for positioning in the desired points as the nodes' latitude.

ii) Link file: The creation of each edge (as a road segment for connecting the junctions) requires the election of two junctions which are defined in node file. Link file includes edges' information such as id, type, direction, start and end nodes (junctions).

iii) Link property file: Additional information regarding each edge or link such as lanes priority based on traffic regulations, number of lanes, and speed limit of lanes can be defined in an additional file named link property file.

iv) Traffic movement file: In order to change the default settings of SUMO such as allowed U-turn or connection between the rightmost lanes of each link as well as to specifying traffic movements and lane connections an additional file named traffic movement file is required in SUMO.

After preparing four aforementioned files according to traffic scenario and road map, it is required to generate the network file from them to make the conformity of configured files with SUMO traffic generator format. NETCONVERT command line is used for achieving this objective. The figure 6.1 illustrates the sample of using NETCONVERT command for generating the SUMO network file entitled "*XXX.net.xml*". As it can be seen *.net.xml* extension is used for Network files in SUMO.

```
Netconvert –node-files=XXX.nod.xml –edge-files=XXX.edg.xml –output-file=XXX.net.xml
```

Figure 6.1: Netconvert Command Line

It is worth noting that SUMO can generate road networks and maps either by using an application called "*netgenerate*" or importing a digital road map via "*netconvert*" as follows:

- *Netgenerate*: This application is a tool for generating different types of maps. The NETGENERATE eliminates the requirement of configuring the Node and assist in constructing the three kinds of abstract networks including the manhattans-alike "grid network", circular "spider network" and "random network".
- *Netconvert*: As mentioned before, Netconvert is a command line application that enables the users and developers to build various road network topologies. It can be used for generating simple road maps by using node and link files or for generating complex and real road maps by importing them from other traffic simulators such as VISUM (PTV, 2006) and MATSim (Multi-Agent Transport Simulation (MATSim) hompage, 2008) or from open source digital maps such as shapefiles (Stabler, 2006) and OSM (Bennett, 2010). The OSM project as the most cited and used digital maps source using by NETCONVERT.

After creating Network file (i.e. *XXX.net.xml*), Traffic demand file is another required file in order to generate the traffic simulation scenario in SUMO. Traffic demand file includes any information regarding the movement of vehicles beside their types, their quantity, their features and the routes that are required to utilize in the provided network file. Traffic demand file should be stored by *rou.xml* extension. After obtaining the Network file and defining the Traffic demand file, we need to attach all the prepared files together into a file, called configuration file, which includes both rou.xml and .net.xml. files as well as simulation duration. Configuration file should be stored by *sumo.cfg* extension.

Traffic simulation execution can be achieved by categorization the configuration file in two ways, namely SUMO and GUISIM (SUMO-GUI). SUMO application is a pure command line application for efficient batch simulation, while, GUISIM (SUMO-GUI) is the extended application for SUMO which provides the graphical user interface for the simulation. The SUMO-GUI assists the user to observe and monitor the simulation in action. This visual application can be customized in order to show the vehicles speed and waiting time or to follow the traffic behaviour of specific vehicle. Polygons, Point Of Interest and image decals are some other graphical features that are exist in GUISIM (SUMO-GUI) to enhance scenarios' visual appearance. It also brings the possibility of interaction with scenarios by changing the prepared traffic signal programs or rerouting the scenarios. Several output files can be obtained for each simulation run via SUMO (SATTARI, 2015). For all vehicles, there is a written range from simulated inductive loops to single vehicle positions in each step as well as other complicated values such as each vehicle's trip information or aggregated measures for all streets or lanes. In addition, noise or pollution emission as well as fuel consumption can be modeled in SUMO which enables users to evaluate the ecological effects of their proposed protocols or applications for vehicular networks. It is worth noting that all output files generated by SUMO are in XML format. Figure 6.2 represents an overview of simple traffic scenario implementation in SUMO considering the required files.

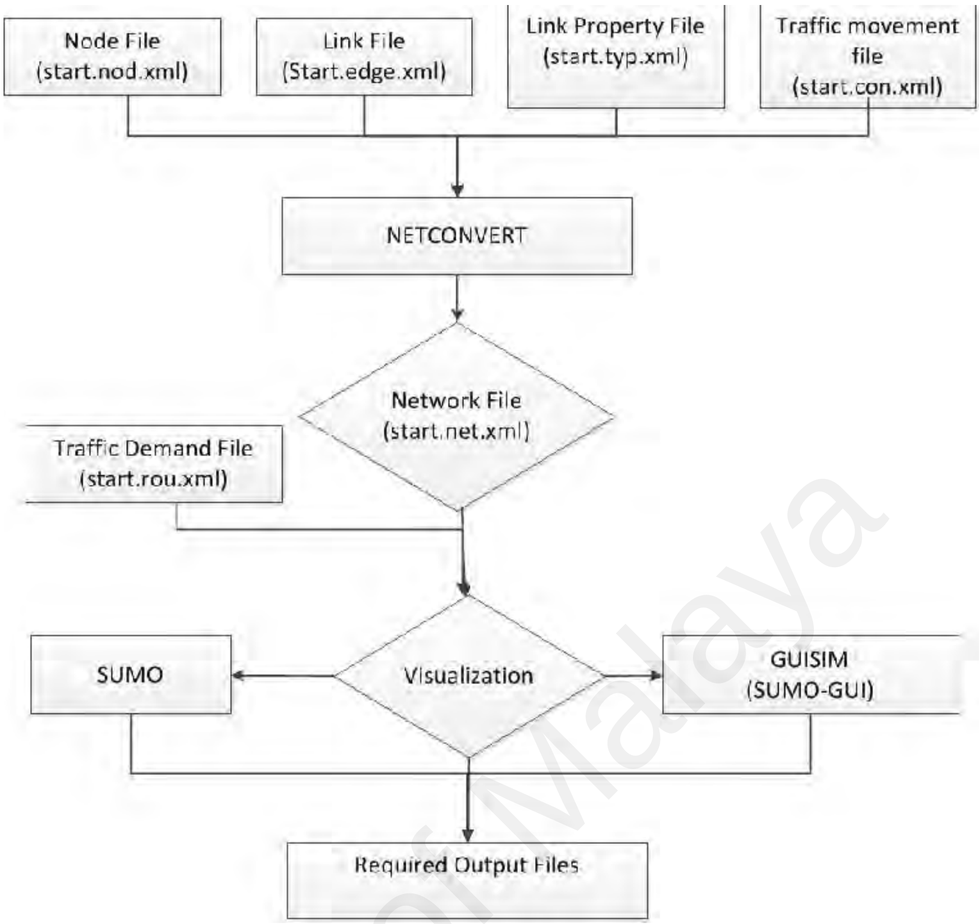

Figure 6.2: General Steps of Traffic Simulation in SUMO

- Traffic and Network Simulation (TraNS)environment

TraNS is a VANET simulator that links SUMO and NS-2 as a mobility generator and network simulator, respectively, to create realistic VANET simulation scenarios. In this way, 1) realistic mobility models can be utilized by NS-2 (i.e. network simulator) and 2) the behavior of vehicles in SUMO (i.e. mobility generator) can be affected and manipulated by NS-2 considering the communication between vehicles. Most of the existing VANET simulators cannot provide the second feature, while the first feature can be obtained by all VANET simulators. TraNS has two different operation modes, namely network-centric and application-centric. The explanation of each of these modes is as follows:

a) Network-centric: Mobility trace files are created and stored on a storage device prior to the network simulator. As a result, this mode can be used for evaluating the protocols that do not effect on vehicles mobility during simulation runtime. User content (e.g. music, file or travel information) exchange or distribution protocol is a suitable example that can be evaluated in this mode.

b) *Application-centric:* This mode enables network simulators to modify the vehicles mobility based on simulated scenario during simulation runtime. Unlike network- centric, the mobility trace files are not created and stored on a storage device prior to the network simulator. This characteristic enables users to create large scale and long-term simulation scenarios without concerning about limited space of storage devices. TraCI is used to interlink mobility generator and network simulator. In other words, both mobility generator and network simulator operate simultaneously and TraCI resides between them and controls their communication. Safety and traffic efficiency applications (e.g. collision avoidance or SmartPark () are proper examples that can be evaluated in this mode. In the following subsection we discuss TraCI in more details since it is one of the main parts of our experimental simulation.

Regarding map preparation module and providing a suitable and realistic traffic mobility simulation which enables rational evaluation of proposed approach, it is required to design and use a real road map in a manner that possess the prominent feature of urban areas especially the central areas, e.g. downtown. These areas generally comprise orthogonal outline of several adjacent intersections to connect road segments together and are the most common areas that suffer from vehicle congestion problem (Jabbarpour, Noor, & Khokhar, 2015). For this aim, OSM application is used to export the main structures of real road map in this thesis. OSM is the online editable source of the world map that includes most of road attributes comprise of speed limits, traffic lights, turn restrictions, road types, and etc. OSM provides manual selection of the desired area by using the available option for exporting it as the *.osm* files. A part of the city of Kuala Lumpur, Malaysia map is extracted from OSM in the form of *XML* formatted *.osm* file, namely *map.osm*, and used as the physical road map layer in our simulation which is illustrated in Figure 6.3.

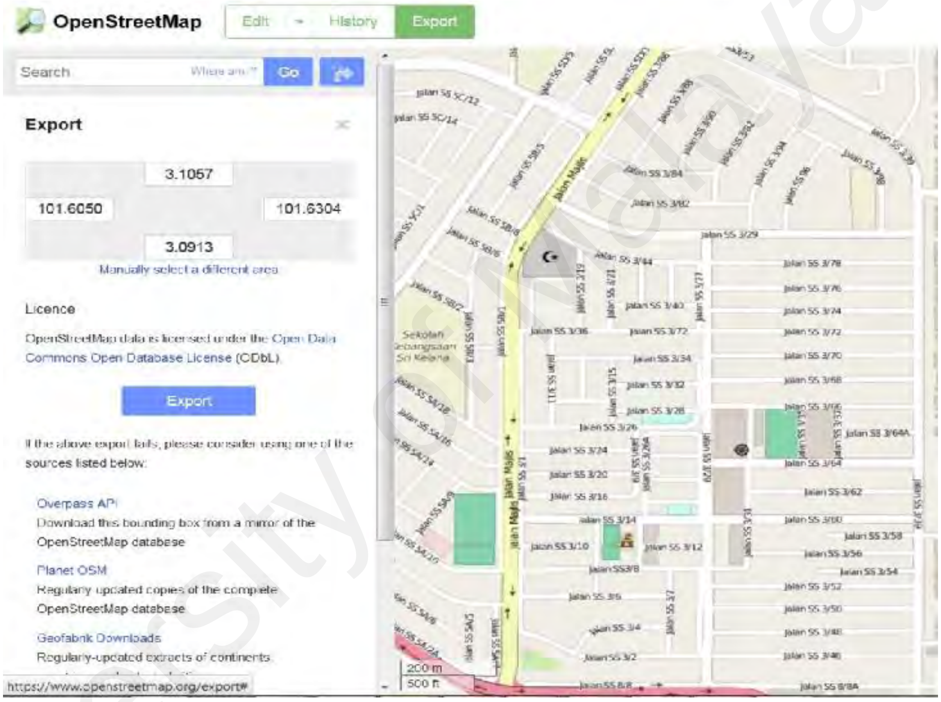

Figure 6.3: The Exported Road Map from OSM Application

The map.osm file converts into suitable SUMO format by using NETCONVERT tools. The NETCONVERT command line that used for converting *map.osm* file into the *map.net.xml* file. The obtained *map.net.xml* file is imported into SUMO and the result is illustrated in Figure 6.4.

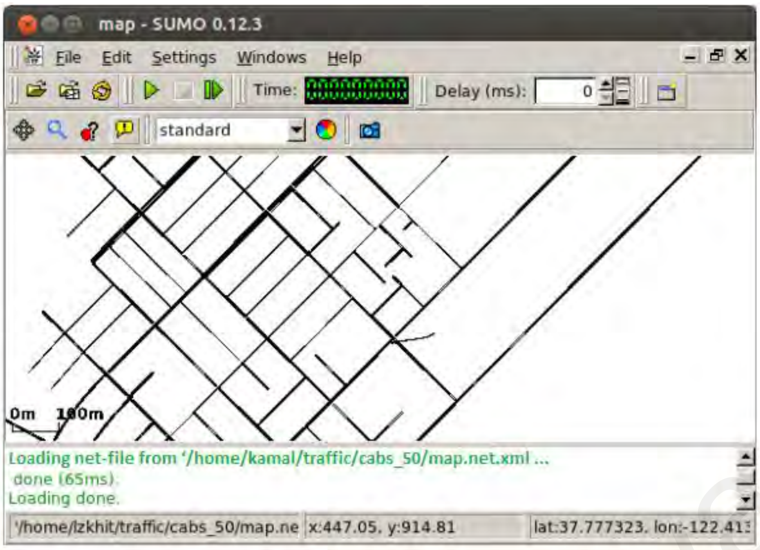

Figure 6.4: The Extracted Road Map in SUMO

In addition to net file, node, edge and connection files are also needed in order to implement the layering and segmentation sub-modules of map preparation. These files are also required for vehicle movement simulation due to following reason. A vehicle from source to destination is assigned by the user in SUMO. Hence the simulation is difficult task due to large number of vehicles and complex road map. In order to solve this problem, TrafficModeler (), an open source tool with easy-to-use graphical user interface, is used for quick and high level modeling and generation of vehicles movements in this thesis. The Netconvert command line is used to obtain *Map.net.xml*. Meanwhile, Netconvert command with –plain-output option is used to obtain the other required files (i.e. *map.nod.xml*, *map.edg.xml* and *map.con.xml*). After importing the road map into TrafficModeler, we generate various vehicle traffic models by using traffic layers, traffic generation algorithms and graphical user interface according to our simulation scenarios.

6.2.2 Phase-II: NS-2 for Network Simulation

NS-2 is a discrete network simulator that provides significant simulation of transport, routing, and multicast over-wired and wireless networks. NS-2 code is written using C++ and OTcl and is kept in a separate file that is executed by OTcl interpreter, thereby generating a communication trace file and a Network Animator (NAM) file as its output. The output trace file describes the network topologies and log events that display the output of the nodes communicating with each other. The NAM file animates the traces derived from the simulation and analyse the events to comprehend the network behaviour. NS-2 may be installed over either LINUX or any UNIX-based operating systems. Once installed, have to write (or edit the supplied one from the set of examples) the file in OTcl script language and execute NS with this file as an input. This OTcl file incorporates traffic generator trace file from SUMO and other communication parameters like routing protocol, CBR (constant bit rate) etc. for using them in the simulation. The figure-6.5 show the input/out flow chart of NS-2 simulation process, the OTcl script for NS-2 simulation comprises inputs for event scheduler objects and network component objects including the nodes' mobility traces derived from SUMO.

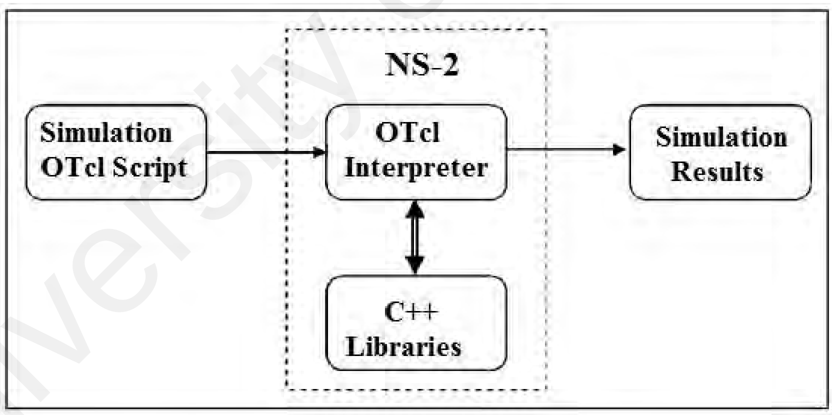

Figure 6.5: NS-2 Simulator Interaction with OTcl Script

6.2.3 Phase-III: NS-2 Trace Analysis

The generated NS-2 output trace file and network animator NAM file, is visualize node movement behaviour. Finally, useful information from the trace data file are extracted and plotted in performance analysis.

6.2.4 NAM-file visualization

A generated NAM file is used to analyse the packet level simulation and visualize the network topology. The routing path of packet and how they queued transmitted or dropped can also be examine the NAM file. It can also monitor individual nodes, links or packets.

6.2.5 Trace File Analysis

The generated communication trace file from NS-2 simulation is essentially a text file compiling a large amount of information. It is necessary to understand the data provided in different fields (column) of the trace file in order to extract appropriate information and plot them for analysis. Mostly the awk tools is used to extract requisite information from the trace file. The data file generated from the output trace file of NS2 using awk, OTcl, Matlab or any other script can then be used to plot then in xgraph, excel graph or Matlab etc.

6.3 Experimental Setup

The simulation environment consists of three logical components, as shown in figure 6.6

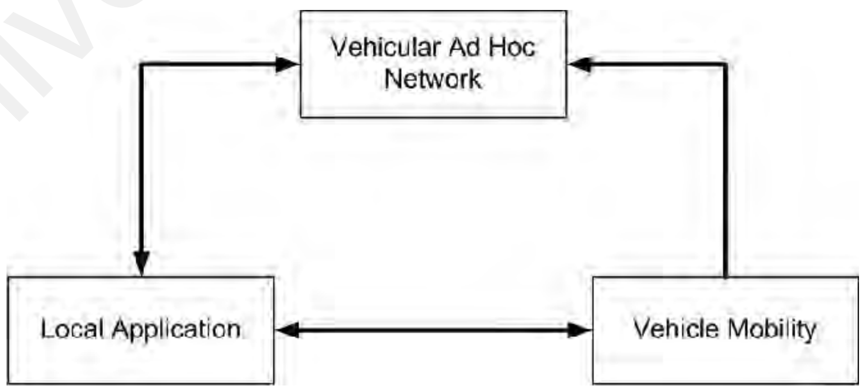

Figure 6.6: Simulation system overview

The vehicle mobility component depicts the periodic computation of a new position within a confined geographic space in which the mobile vehicles are contained. This component may be implemented by a traffic simulator. The VANETs constitutes the second component, which is dedicated to imitating the full functionality of a real vehicular network with all of the complex effects related to DTN. Only a portion of the vehicles defined by the traffic simulator participates in the VDTN, which mimics the partial deployment stage of VANETs on the road. The other vehicles play a specific role in traffic considerations but are considered to be unequipped and hence do not participate in the ad hoc network communication. The third component is the local application, which is accountable for the control of the whole simulation environment. The local application operates in the same manner in all vehicles, it evaluates the received messages, and able to generate new messages and adaptively broadcast them via the network. The application relies on up to date information about the current vehicle positions, vector and DIL information which are provided by the vehicle mobility module. The local application was integrated into the network simulator as an additional module which simplified the implementation because communication links are necessary, only between two simulators, as depicted in Figure 6.7.

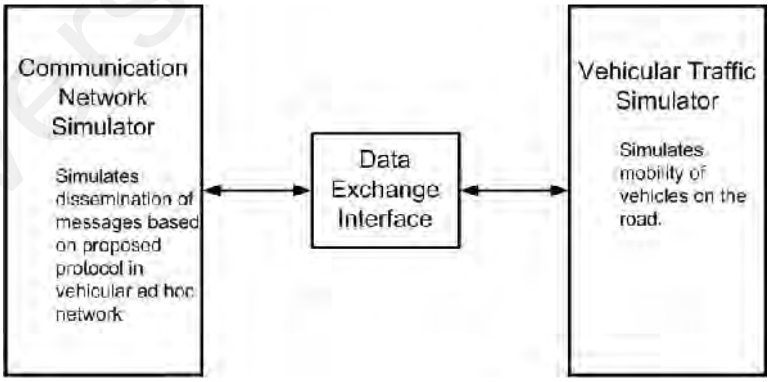

Figure 6.7: Interaction between the network and traffic simulators

The simulation environment consisted of both a network simulator and a traffic simulator. The network simulator acts as a client requesting information from the traffic simulator. For example, it needs to know both the exact number of cars that are part of the network and their geographic positions within the scenario. The traffic simulator, on the other hand, acts as a server and sends all requested information to the network simulator. In summary, the simulation environment required a high level of accuracy for the communication network and a lower level of accuracy was sufficient for simulating vehicle movement. Two different scenarios are implemented to evaluate AGDR performance in VDTN; Intersection and Freeway Mode. In real world a road map consist of intersection and freeway, so we simulate these two scenarios. Despite most protocols proposed VANET routing protocols in usual nature, we felt special attention is essential to deal with freeway scenarios. It is assumed every driver will ideally use the direction indicator light to change the direction. In response to the limitations of RWM, more researchers have become interested in modelling 'realistic' mobility patterns for VANETs. Both road map topology and vehicle density are key points in the simulation environments and they highly affect the accuracy of the obtained results. With regard to the road map topology, we used a complex real road map of Kuala Lumpur city in our simulation to obtain closer results to real intersection environments. In consideration of vehicle density different vehicle densities ranging from 10 to 150 vehicles. We have utilized TrafficModeler to generate vehicular traffic and movements. Various numbers of vehicles are generated and located on each of the desired origin points. The number of vehicles in each origin point varies from 10 to 150.

6.4 Simulation Environment of the Routing Protocol

In order to fit the simulation environment of the routing protocol, each node in the network includes a set of network components, which must be declared. It includes parameters such as antenna type, the model of the radio propagation and the data forwarding techniques. The simulation parameters are set close to the real scenario. The antenna type is set to Omni-directional with free space propagation model to simulate the proposed routing protocol. Three different scenarios have been applied to simulate the proposed protocol using the above mentioned metrics. The scenarios encompass a variation in the number of nodes 10, 20, 40, 60, 80, 100, 120, 140 and 150. A CBR traffic generator is used for analysis. Each simulation was executed for 250 seconds of simulation time. The deploy area for each simulation was chosen as a 4000m x 3000m rectangle area, representing a street. The CBR is set to vary from 0.1 to 1.0 as a network traffic model. The speed of the vehicles varies from 0m/s to 35m/s in this simulation. The proposed protocol simulate under the three different scenarios for analyse the performance metrics. The performance of the routing mechanism can be affected by other factors as well. It includes mobility model, traffic pattern and the driver behaviour. To evaluate the performance of AGDR protocol, the ratio of delivered packet, generated overhead traffic and average time delay metrics are used.

The parameters for prescribing the value of implementing the AGDR are listed in table 6.2.

Table 6.2: Simulation Setup

Parameters	Network Size	Data Packet Size
No. of Nodes	10, 20, 50, 100, 150	10, 50 ,150
Max. Vehicle Speed(m/s)	25	25
Simulation Time (s)	250	250
Network Space (sqm)	4000×3000	4000×3000
Transmission Range(m)	250	250
Radio Propagation Model	Free Space Propagation	Free Space Propagation
Data Packet Size (Bytes)	500	500,1000,2000,3000, 4000
Antenna Model	Omni Directional	Omni Directional
Traffic Pattern	CBR	CBR
Vehicle Beacon Interval(s)	0-5.0	0-5.0

6.5 Simulation Metrics

To make an examination of the performance of this routing protocol, based on appropriate metrics, compare the simulation result from the AGDR with two routing protocol of same domain GPSR and GeoOpps. In order to obtain a fair comparison, re-simulate the GPSR and GeoOpps routing protocol in the same environment as used to simulate the AGDR, and show the comparison results based on performance metrics. The reasons behind the selection of these two routing protocol as both two fall in the same routing class DTN. GPSR routing protocol consider as the benchmark in the geographic routing and GeoOpps routing protocol take the advantage of GPS, digital road map and some other parameter close to AGDR. The simulation result has been analysed by comparing three different metrics to examine the performance of the routing protocol, these metrics are as follows:

6.5.1 Packet delivery

Packet delivery is a very important factor to measure the performance of routing protocol in any network. The performance of the protocol depends on various parameters such as are packet size, no of nodes, transmission range and the structure of the network chosen for the simulation. The packet delivery ratio can be obtained from the total number of data packets arrived at destinations divided by the total data packets sent from sources. In other words Packet delivery ratio is the ratio of number of packets received at the destination to the number of packets sent from the source.

6.5.2 Packet Overhead

Packet overhead computes the accumulated number of control packets transmitted over the network. It is calculate the total number of control packets that are sent during the processing of transmitting the data to its destination. The unit of this metric is the number of packet and lower the number of packet overhead higher the network performance.

6.5.3 Average End-To-End Delay

Average end-to-end delay is the time taken by a packet to route through the network from a source to its destination. The average end-to-end delay can be obtained computing the mean of end-to-end delay of all successfully delivered messages.

Therefore, end–to-end delay partially depends on the packet delivery ratio. As the distance between source and destination increases, the probability of packet drop increases. The average end-to-end delay includes all possible delays in the network i.e. buffering route discovery latency, retransmission delays at the MAC, and propagation and transmission delay. The classical unit of this metric is millisecond (ms). For this metric, lower the time taken, more privileged the routing protocol is considered.

6.6 Results and Discussion

We compare the performance of AGDR with the GPSR and GeoOpps using relevant communication metrics: packet delivery ratio, packet overhead and end-to-end delay by varying the network size and data packet size.

6.6.1 Simulation Result by Varying Network Size

The results were considered for varying network sizes (number of node) that corresponds to the number of vehicles. In figure 6.8 and figure 6.9, shows the number of delivered packet of AGDR protocol compares to two others protocol GPSR and GeoOpps in the intersection mode and the freeway mode. Figure 6.8 and 6.9, depict a noticeable improvement of AGDR's number of delivered packet and packet overhead than GPSR and GeoOpps in both the modes. It is due to the next-hop selection process that considers DIL information and selects relay vehicles even on opposite lanes if a suitable relay is not found in the same lane. It has shown that in intersection mode the packet delivery rate is slight higher than free mode especially when vehicle density is low.

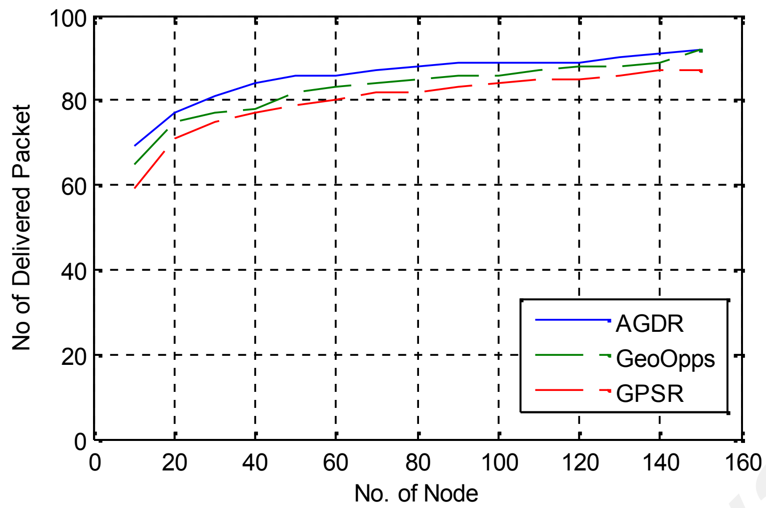

Figure 6.8: Packet delivery Vs Network Size for Intersection

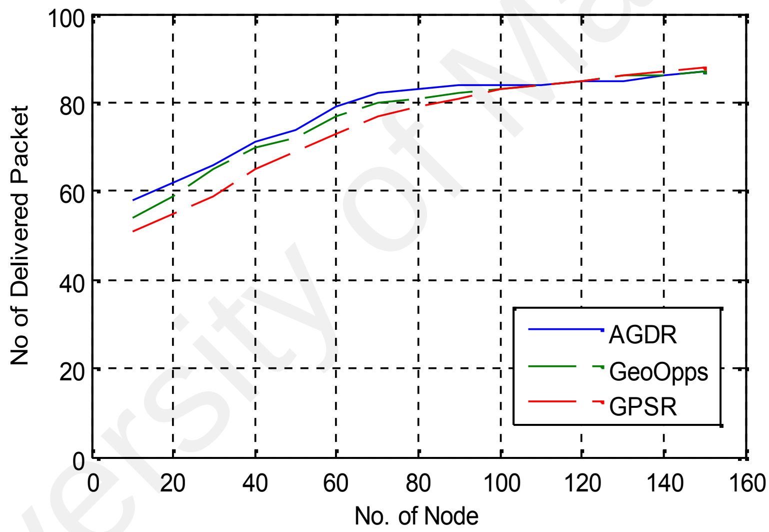

Figure 6.9: Packet delivery Vs Network Size for Freeway

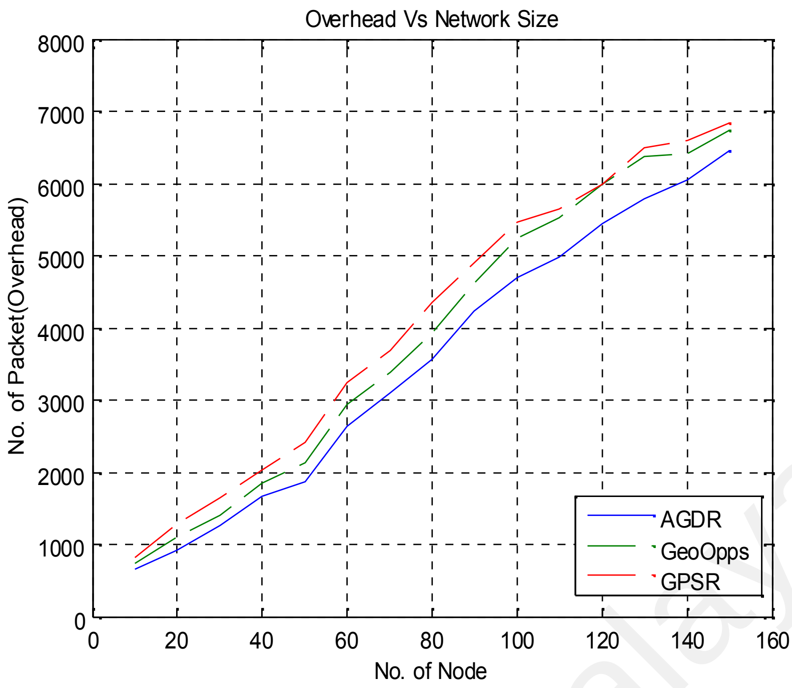

Figure 6.10: Packet Overhead Vs Network Size for intersection

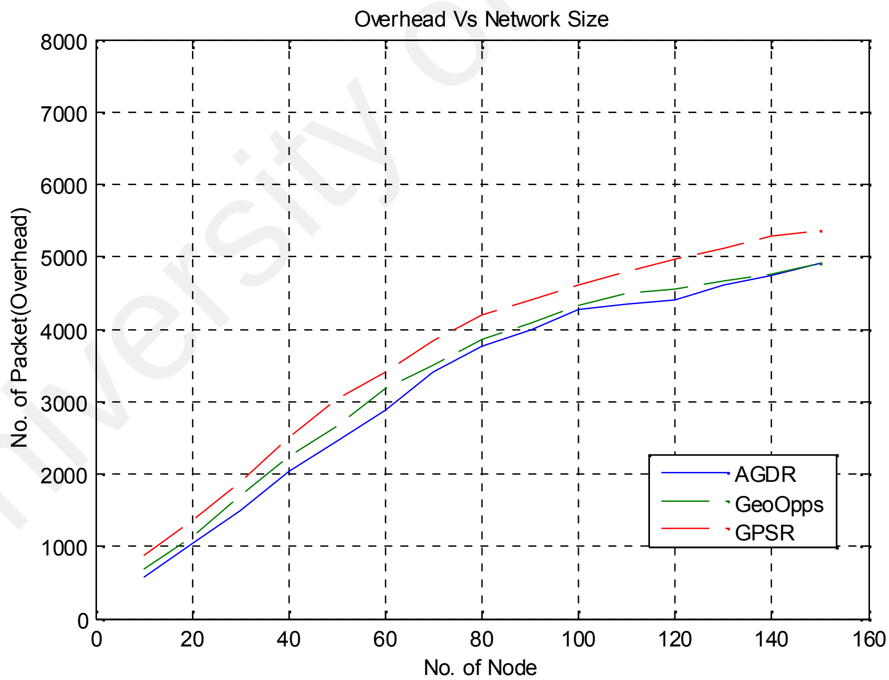

Figure 6.11: Packet Overhead Vs Network Size for freeway

Figure 6.10 and 6.11 shows the overhead of three routing protocol for intersection mode and for freeway mode. From the figure 6.6 in intersection, linearly increase the number of control packet with respect to increase in network size (number of node). From the figure 6.11 for freeway it generates lower number of control packet than intersection. The overhead for AGDR protocol is lower than other two protocol GPSR and GeoOpps. Figure 6.12 is for the end-to-end delay for increasing number of node. From the Figure 6.12 and Figure 6.13 we find that the AGDR's delay is minimal for low network size i.e. less than 60 nodes comparing to GPSR and GeoOpps. However, for more than 100 vehicles, end-to-end delay is similar in all three protocols. This similarity is due to the reduction of route failures of GPSR and GeoOpps for increasing number of node.

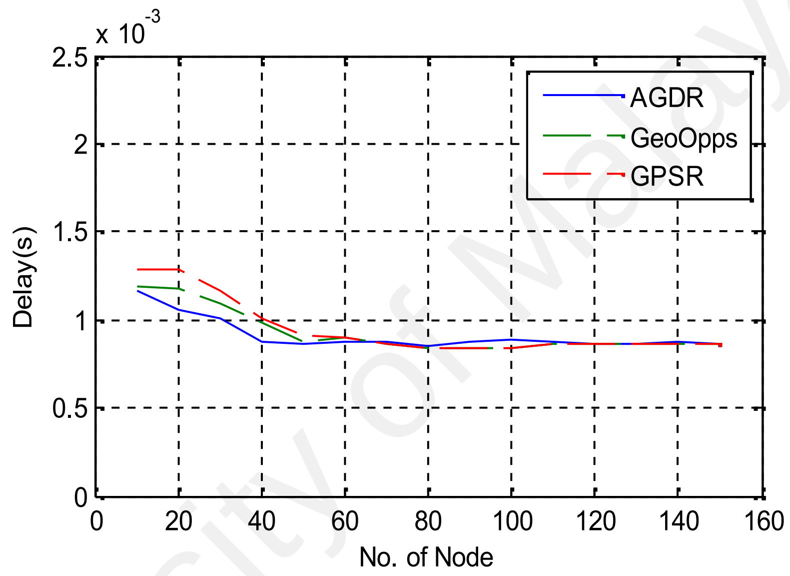

Figure 6.12: Delay Vs Network Size for intersection

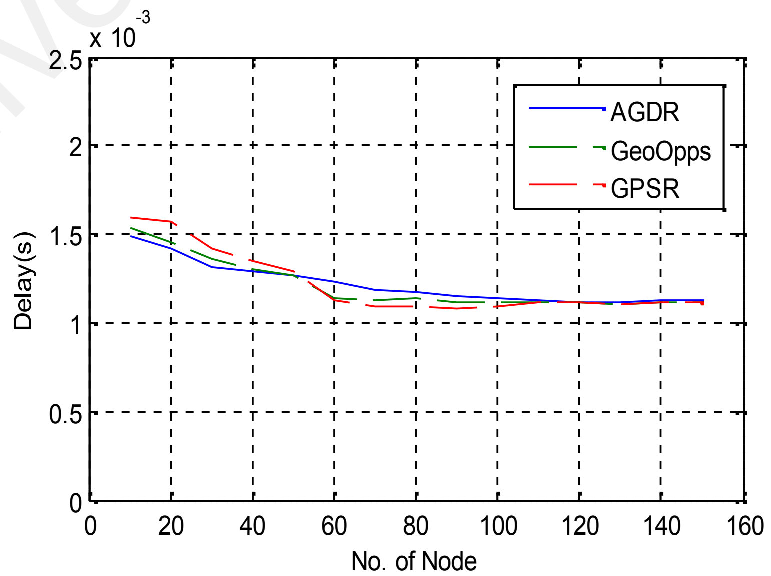

Figure 6.13: Delay Vs Network Size for Freeway

In other words, it shows that for vehicular networks with fewer vehicles and possible network partitions, AGDR is a more suitable communication option.

6.6.2 Simulation Result by Varying Data Packet Size

In this section the performance of AGDR is analysed in terms of the data packet delivery, number of packets sent through the network and time delay by varying the data packet size. The figure 6.14 and figure 6.15 represent the number of delivered data packet versus an increase in the size of the data packet for intersection and for freeway mode. As we can see from the figure 6.15, the delivered data packet shows a slight decrease, which then becomes settled with the increase in data packet size for the same number of packets. The both figure 6.14 and figure 6.15 indicates that the performance of AGDR is superior to GPSR and GeoOpps in terms of packet delivery for the use of DIL information in the forwarding process.

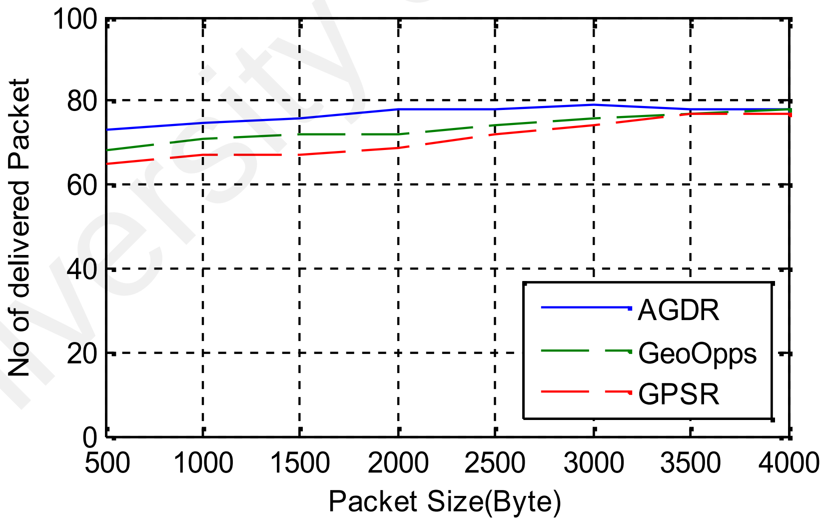

Figure 6.14: Packet delivery Vs Packet Size for Intersection

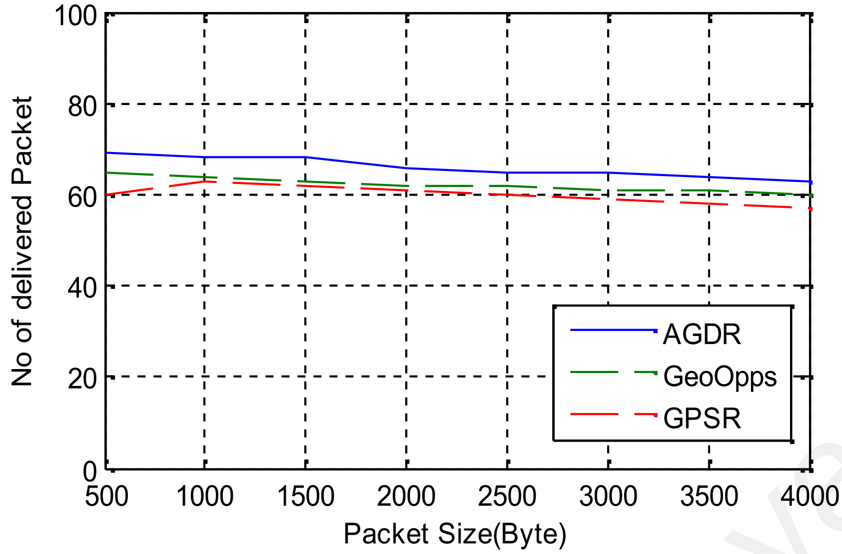

Figure 6.15: Packet delivery Vs Packet Size for Freeway

Figure 6.16 illustrates the impact of varying the data packet size on the number of packets sent through the network (Overhead). The figure 6.17 shows that the overhead is stable by increase the data packet size. Bandwidth consumption is more depend on data packet size. The figure 6.16 and figure 6.17 advocates that AGDR perform better than GPSR and GeoOpps. This derives from the fact that it utilized the aspect of the packet to its destination, which has an impact on reducing the overheads.

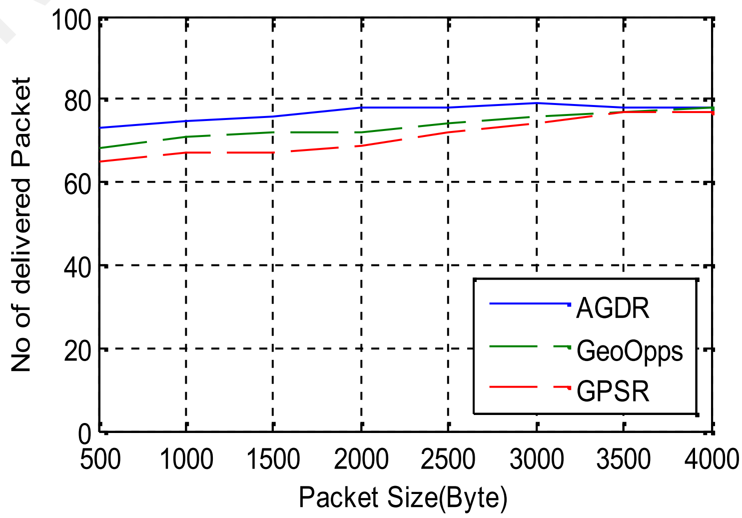

Figure 6.16: Packet Overhead Vs Packet Size for Intersection

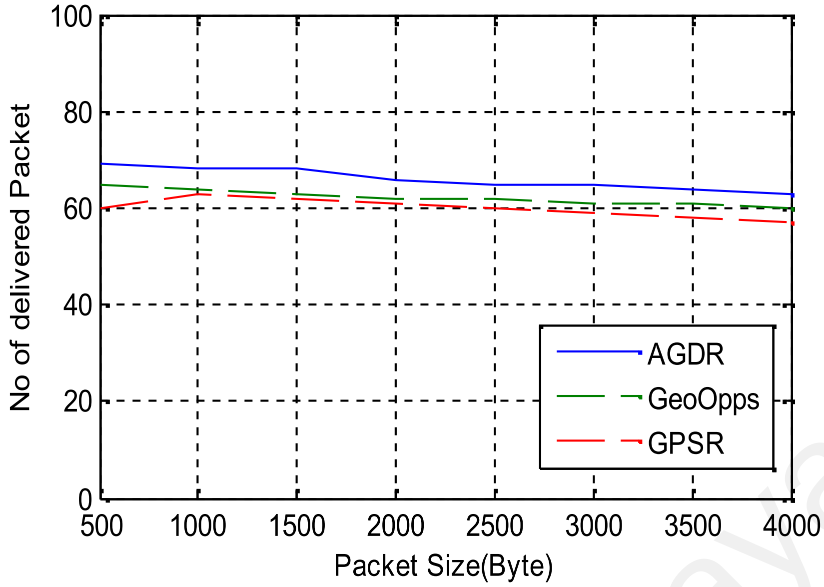

Figure6.17: Packet Overhead Vs Packet Size for Freeway

The figure 6.18 and figure 6.19 show the end-to-end time delay against increasing the data packet size for intersection mode and for freeway mode. Both figure 6.18 and figure 6.19 shows the GPSR and GeoOpps shows a slight increase in end-to-end time delay compared with the AGDR providing less time when increasing the data packet size. This occurs because of the traffic generated in GPSR, which leads to the retransmitting of some packets causing an increase in delay, while in AGDR the decision about forwarding the packet to the next-hop node was more accurate, taking the other factors into account like the DIL information.

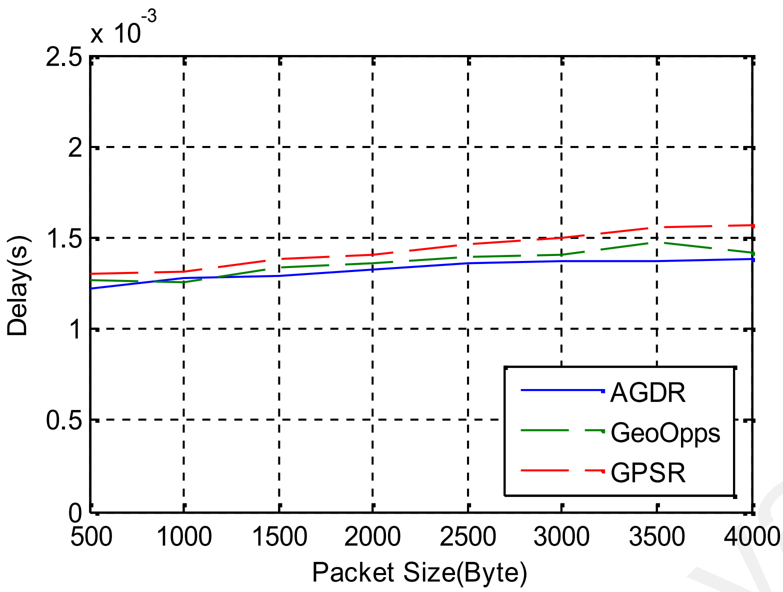

Figure 6.18: Delays Vs Packet Size for Intersection

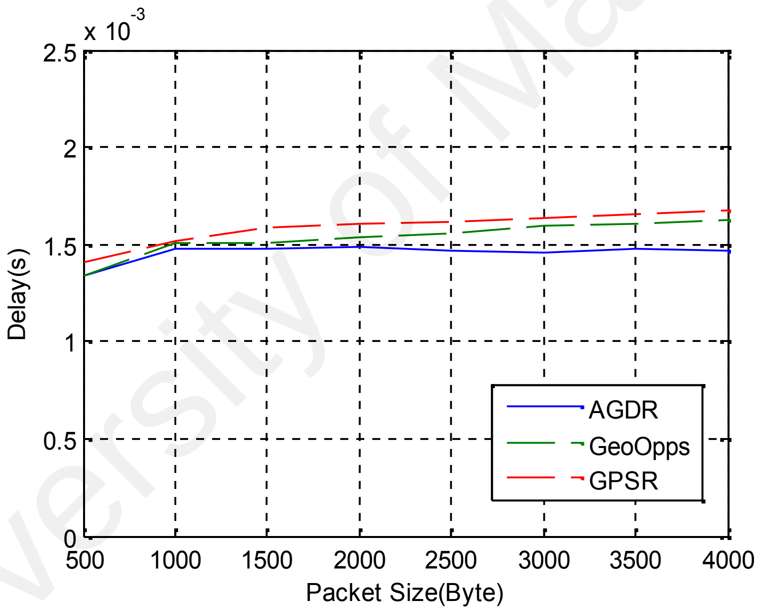

Figure 6.19: Delays Vs Packet Size for Freeway

6.7 Effect of the Hello Interval

The adaptive HELLO beacon message acts as the heartbeat of the system and therefore must be used carefully. Every node in the network transmits a HELLO beacon message adaptively based on the parameter value. Intended receivers of this HELLO message are the immediate one hop neighbours of the transmitting node. The packet itself is a very short derivative of the complete header, containing only the information about the transmitting node. On receiving the HELLO packet the neighbouring nodes simply update their neighbour list and then discard the message. The HELLO packet plays an important role in the performance of the routing protocol. The HELLO packet provides the receiving node with the most recent correct geographic location, vector information of the vehicle and the predicted future direction from DIL. All forwarding decisions are based on this collected information.

6.7.1 HELLO beacon message period intervals to the number of packet delivered

Figure 6.20 and 6.21 shows the Packet delivery with respect to HELLO beacon message broadcasting interval for intersection and freeway respectively. The figure 6.20 represents an initial linear decrease for the AGDR then it starts to settle in the passes of time of broadcasting for the intersection. The figure depicts a considerable improvement of the data delivery of AGDR over GPSR and GeoOpps. A significant decrease in the beginning of the figure is considered to be a consistency of varying the HELLO beacon messages intervals. The interval of broadcasting HELLO beacon message is considered to be less in beginning area. The vehicular nodes collect latest information about surrounding nodes hence show a significant change.

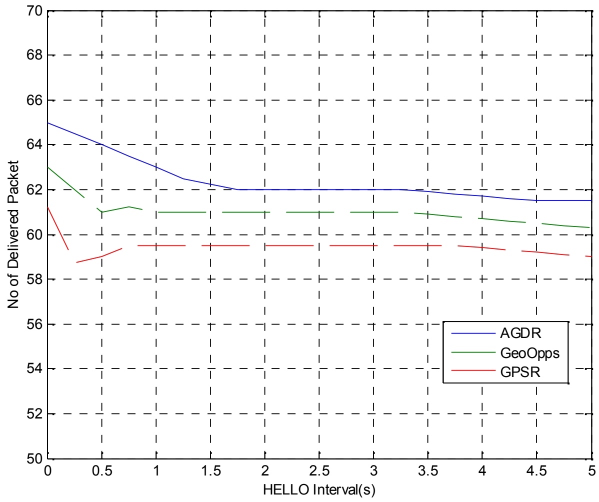

Figure 6.20: The Packet delivery against the beacon message intervals for the intersection

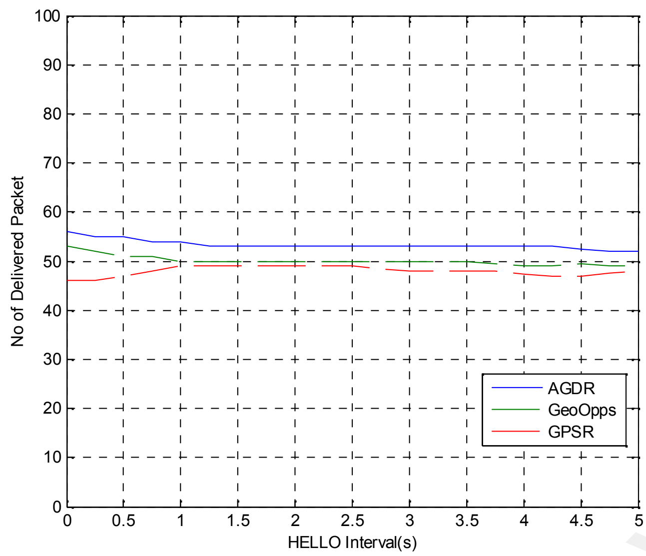

Figure 6.21: The Packet delivery against the beacon message intervals for the freeway

6.7.2 HELLO beacon message period intervals to overhead

The figure 6.22 and 6.23 represents effect of HELLO beacon message interval on the data packet overhead. The both the figure illustrate the packet overhead is noticeable decreased with the increasing the time interval as it need fewer control packet to maintain network when it was long HELLO beacon interval. AGDR need less packet overhead than GPSR because of it use DIL information for next-hop selection process to find the best intermediate node.

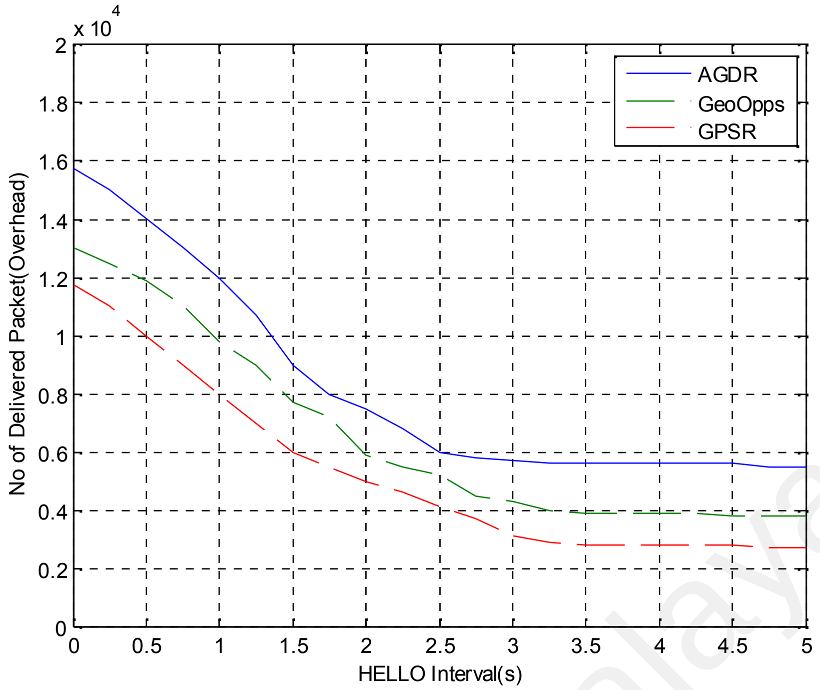

Figure 6.22: Overhead against the beacon message intervals for the intersection

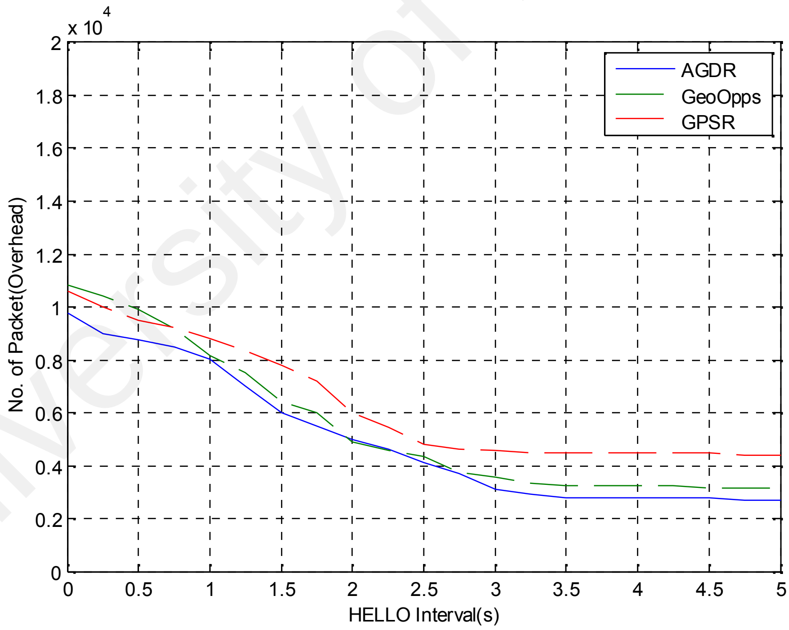

Figure 6.23: Overhead against the beacon message intervals for the freeway

6.7.3 HELLO beacon message period intervals to end-to-end delay

Figure 6.24 and 6.25 illustrates the end-to-end time delay verses the HELLO beacon broadcasting time interval. The AGDR shows less delay than GPSR and GeoOpps when increasing the period between the sending of the HELLO beacon message. AGDR and GeoOpps show the same delay period for freeway mode.

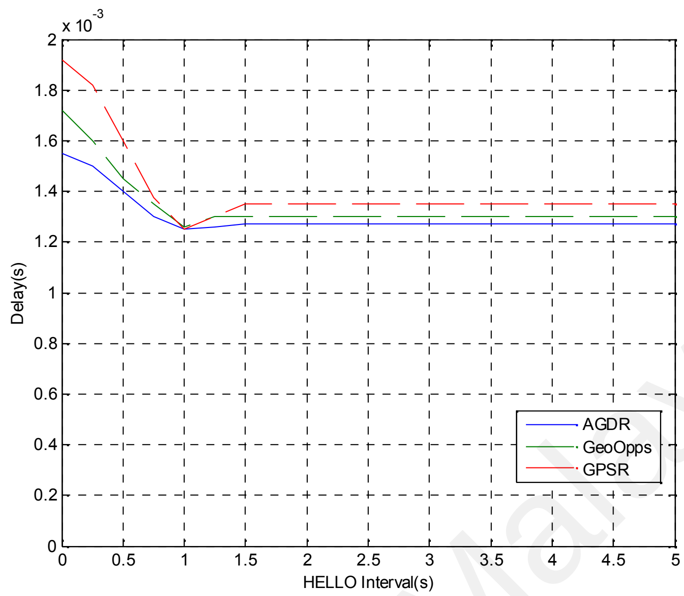

Figure 6.24: End-to-end delay against the beacon message intervals for the intersection

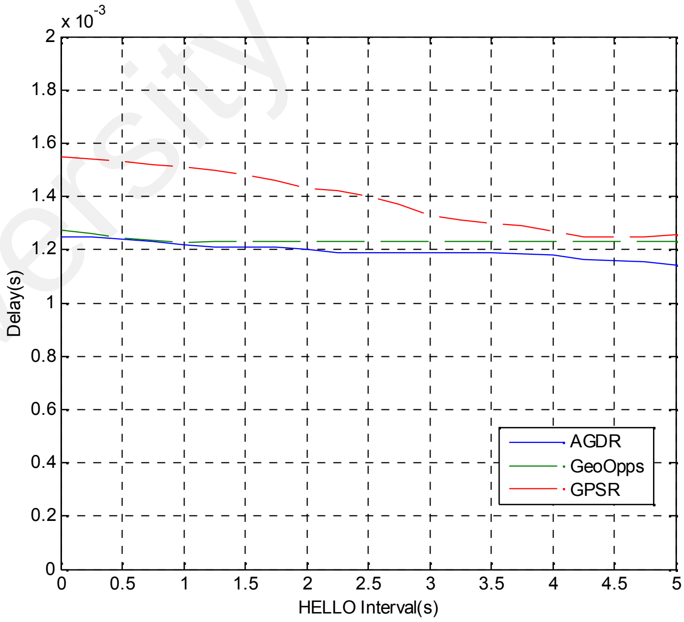

Figure 6.25: End-to-end delay against the beacon message intervals for the freeway

6.8 Validation of AGDR Simulation Result

To be sure that the model gives a good approximation to the results which we get by simulation, need to validated them. The comparison of simulation result with the benchmark, can see that all analytical and experimental curves have a very similar trend. Taking into account that the model and the simulated environment have several differences (simulated area and mobility, among others), some deviation is expected. However, we can see how the results are mostly identical in many cases. The results for the AGDR routing are closely related to GPSR and GeoOpps routing, with differences are acceptable level. This difference comes from the number of nodes which need to validate use different parameter for selecting the forwarding node consider for the AGDR routing protocol. In AGDR routing protocol used real time road and vehicle parameter, hence model predicts more pessimistic results than GPSR and GeoOpps obtained by simulations. Adaptive models also offer very similar values, and the main differences are because in AGDR routing approximated the overhead without considering that nodes dynamically enter and leave the network. In any case, differences are small enough to serve as a validation of AGDR routing protocol.

6.9 Conclusion

Computer simulation is necessary in analysing mathematically intractable systems and is used to investigate system performance prior to real-world deployment. This chapter has discussed computer simulation modelling and described the constituent models used to implement the data forwarding technique for adaptive vehicular delay tolerant network. When designing a computer simulation environment accurate modelling must be used. The NS-2 simulator is a network centric simulation environment designed specifically for the analysis of VANET networking protocols. NS-2 is built using realistic models to underpin the accuracy of the simulation environment. Channel model parameters have been estimated based on empirical measurements captured in urban and freeway environments using IEEE 802.11p radio interfaces. Realistic mobility modelling is critical for the analysis of VANET broadcast protocols as the performance of a broadcast protocol is strongly correlated with mobility. To generate mobility patterns that are reflective of realistic movement the mobility model implemented as part of the simulation is based on real world map topologies.

CHAPTER 7: CONCLUSION

This chapter concludes the thesis with a summary of the adaptive delay tolerant routing in vehicular environments after which the original contribution of the research is listed. Finally the achieved aims are specified and future direction for the further extension in carrying out research of delay tolerant types in vehicular ad hoc network are given.

7.1 Summary

A DTN is a special kind of VANET which is characterized by its intermittent connectivity and high velocity of nodes. A number of fatal accident on the roads, reason behinds the traffic congestion and vehicle collision made government, researcher and car manufacturer to concentrate on improving the research domain of ITS, in an attempt to reduce the percentage of fatal accidents occurring on the roads. The proposed AGDR protocol is focused to find a robust route packet to the desired destination in the DTN, in order to increase the connectivity and stability, which then lead to increase in network reliability, in terms of increasing delivery ratio, reducing overhead and time delay. By solving those problems this will lead to achieving the main aim of increasing the efficiency of safety applications in VANETs, and that is accomplished by improving the routing management in VANETs. This aim is achieved by contributions introduced in this thesis. The proposed protocol is utilised a new parameter called the DIL information, which represents the vehicle future direction that's intended to go. A next-hop selection process is utilised in this protocol to select the next hop node, which consider vehicle position, vector and DIL information. AGDR show the flaw of the packet from the source to the destination in two different scenarios, the intersection mode and the freeway mode. Simulation experiments confirm the performance supremacy of AGDR compared to contemporary schemes in terms of packet delivery ratio, overhead and end-to-end delay. Simulation results demonstrate that AGDR improves the packet delivery ratio (5-7%), reduces the overhead (1-5%) and decreases the delay (0.03 to .05 ms). Therefore, AGDR improves route stability by reducing the frequency of route failures.

7.2 Contributions

The first contribution is introduced as a new technique for organising the broadcasting of the HELLO beacon message in VANET by making it adaptively rather than periodically, based on the circumstances of the vehicle such as position, vector and DIL information. Any change at least in one of these factors will lead to a change in the network topology, and then the HELLO beacon message is needed to be sent, to inform other vehicles in the networks about its new situation. As a result this technique works on eliminating the unnecessary and redundant messages, which led to a reduction in the generated overheads.

Another contribution is the novel OBU framework, is presented in chapter 4, which is built based on the technique of the adaptive HELLO beacon message, this framework is utilised the concept of the DIL information first time in VANETs.

The third contribution is introduced in chapter 5, where a new routing protocol AGDR is developed for sparse environment in VANET, where the network density is considered to be low, which create a region of communication gaps between vehicles in the network, that means no vehicles is available to act as intermediate node, which preventing sent packets to be delivered to their destinations.

7.3 Achieved Aims

The research objectives illustrated in Chapter 1 were achieved as follows:

i) Reviewed the state-of-the-art VANET routing protocols, finding the gaps in DTN, defined the problem statements as discuss details in Chapter 3.

ii) The unnecessary and redundant messages are reduced by novel technique adaptive HELLO beacon procedures.

iii) A novel framework was introduced, which designed based on the WAVE and built for sending the HELLO beacon message adaptively in VANET rather than periodically.

iv) Increased the network connectivity and reliability by using the innovative DIL information for the selection of appropriate intermediate node by introducing the next-hop selection procedure.

v) By using the NS-2 simulator, the performance of the proposed routing protocol AGDR has shown a better performance over GPSR and GeoOpps, in terms of delivery ratio, overhead and time delay, which led to increase route link stability.

7.4 Future Work

Many issues in this field still need to be resolved. The adaptive HELLO messages in VANET can be further improved with inward examinations into the selection of parameters that reflect the vehicle circumstances. Moreover, a security platform is required to ensure no exploitation of the DIL information to intrude or influence other vehicles' movements. From the infotainment point of view, our routing protocol (AGDR) can be extended to support multicast traffic as it is the default paradigm for Internet-to-vehicle communications. We also intend to analyse more vehicular data traces to further refine our inter-arrival times model and find other interesting insights such as how to detect and predict the moment of decongestion of a road. Finally, we foresee the application of vehicular traffic state knowledge to the proposed AGDR protocol for the DTN, in order to choose the best configuration parameters according to the current and short term traffic conditions. Many other challenges relate to considerable issues that need to be mitigated such as cross-layer design for the DTN, determining priority sending/receiving and scheduling process in DTN, detecting and analysing drivers' behaviour to resolve safety issues, security and privacy management in the DTN and end-to-end QoS provision for the DTN. To increase the flexibility of the adaptive HELLO beacon message broadcasting scheme, applying fuzzy techniques for improvements. Instead of this, it would be interesting to define different "degrees of membership" to adapt the broadcast scheme consequently. To develop a dynamic mobility model generator. Such application would generate more realistic traffic mobility patterns, making it possible that vehicle's movements could change "on-the-fly" when a warning message is received.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

Article in Academic Journals

1. **Mostofa Kamal Nasir**, Rafidah Md Noor, Mohsin Iftikhar, Muhammad Imran, Ainuddin Wahid Abdul Wahab, Mohammad Reza Jabbarpour and R H Khokhar "Adaptive Delay Tolerant Routing in VANET using Direction Indicator Light Information", in Mobile Information Systems. (Accepted April 2016). (ISI-Cited Publication)
2. **Mostofa Kamal Nasir**, M.A.Kalam, B.M. Masum and Rafidah Md Noor, "Reduction of Fuel Consumption and Exhaust Pollutant Using Intelligent Transport System", Scientific World Journal, (Accepted April 2014). (ISI-Cited Publication)
3. **Mostofa Kamal Nasir**, Syed Adeel Ali Shah, Rafidah Md Noor and Sharmin Parveen, "A Comparative Study and Stepwise Approach for Routing In Vanets", Advances in Natural and Applied Sciences, 8(4) April 2014, Pages: 244-253. ISSN:1995-0772 (SCOPUS-Cited Publication)
4. Syed Adeel Ali Shah, Muhammad Shiraz, **Mostofa Kamal Nasir**, Rafidah Md Noor, Unicast Routing Protocols for Urban Vehicular Networks: Review, Taxonomy and Open Research Issues, Journal of Zhejiang University- SCIENCE C (Computers & Electronics), Doi:10.1631/jzus.C1300332, (IF=0.297, Q4) (ISI-Cited Publication)
5. **Mostofa Kamal Nasir**, Syed Adeel Ali Shah, Rafidah Md Noor, A. S. M. Zahid Kausar and Ahmed Wasif Reza , "Adaptive Delay Tolerant Routing in VANET using Direction Indicator Light Information for Enhanced Connectivity in Urban Scenario" in Wireless Network (Under Review)
6. Michael Oche, Rafidah MD Noor, Christopher Chembe, Mostofa Kamal Nasir and Syed A Ali Shah, "Multi-Constrained QoS Routing for Supporting Real-Time

ITS Multimedia Applications Over VANETs: A Survey” in Computer Communications (Under Review)

Proceeding

1. **Mostofa Kamal Nasir**, Syed Adeel Ali Shah, Muhammad Ahsan Qureshi, Michael Oche and Rafidah Md Noor, Adapting Geographical DTN Routing for Enhanced Connectivity in Partitioned VANETs on Highways, 2014 IEEE TENSYMP - IEEE Region 10 Symposium - Communications Technologies, 14-16 April 2014, Kuala Lumpur, Malaysia (ISI/SCOPUS Cited Publication)
2. Oche Michael, Rafidah Md Noor, Alaa Saleh Al-jawfi, Andrew Thomos Bimba, **Mostofa Kamal Nasir**, "An Automatic Speed Violation Detection Framework For VANETs", IEEE International Conference on RFID Technologies and Applications, 4-5 September 2013, Johor. (ISI/SCOPUS Cited Publication)
3. Mohamed Ahmed, Mohammad Reza Jabbarpour Sattari, **Mostofa Kamal Nasir**, Saeid Ghahremani, Sajad Khorsandroo, Syed Adeel Shah Ali, and Rafidah Md Noor, "Vehicle Adhoc Sensor Network Framework to Provide Green Communication for Urban Operation Rescue", 3rd International Conference on Information and Network Technology (ICINT 2013), 1-2 April 2013, Singapore. (SCOPUS-Cited Publication)
4. Michael Oche, **Mostofa Kamal Nasir**, Abubakar Bello Tambawal, Rafidah Md Noor, Securing VoIP Network: An Overview of Applied Approaches and Analysis, The Pan African Conference on Science, Computing and Telecommunications (PACT) 2013, 15-18 July 2013, Lusaka, Zambia (ISI/SCOPUS Cited Publication)