AN EFFICIENT AND RELIABLE MULTI-HOP ROUTING IN VEHICULAR AD-HOC NETWORKS (VANETS)

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree of

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(With Specialization in Information Technology)

By

SHOBHIT SINGH

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

ROORKEE - 247 667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby declare that the work is being presented in the dissertation work entitled "**An Efficient and Reliable Multi-hop Routing in Vehicular Ad-hoc Networks (VANETS)**" towards the partial fulfillment of the requirement for the award of the degree of **Integrated Dual Degree in Computer Science and Engineering (with specialization in Information Technology)** submitted to the **Department of Electronics and Computer Engineering, Indian Institute of Technology Roorkee, India** is an authentic record of my own work carried out during the period from May, 2011 to June, 2012 under the esteemed guidance and provision of **Dr. Manoj Misra, Professor, Department of Electronics and Computer Engineering, IIT Roorkee.**

I have not submitted the matter embodied in this dissertation work for the award of any other degree and diploma.

Date: June, 2012

Place: Roorkee

Shobhit Singh

(SHOBHIT SINGH)

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: June, 2012

Place: Roorkee

M. Misra

Dr. Manoj Misra
Professor,
E&CE Department
IIT Roorkee, India

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SHOBHIT SINGH

ABSTRACT

A Vehicular ad hoc network (VANET) is a decentralized ad-hoc network, formed of vehicles acting as highly mobile nodes. Recently, vehicular communication systems have attracted much attention, fueled largely by the growing interest in Intelligent Transportation Systems (ITS)[11]. These systems are aimed at addressing critical issues like passenger safety and traffic congestion, infotainment and other value added services. On the other hand, VANETs are also featured by high mobility and constantly changing topology[8]. Due to these features, VANETs are expected to experience frequent network fragmentation, resulting in a very short duration of communication and partially or completely disconnected network. These problems are a crucial research challenges for developing a reliable and efficient routing protocol that can support highly diverse network topologies.

This thesis presents an enhanced routing protocol for urban scenario. The routing protocol proposed in this paper is based on: i) Multi-hop transfer of a single message by discovering the most suitable vehicle within the transmission range instead of using single hop broadcast scheme [20], ii) Dynamic selection of junctions using preloaded digital maps and real time traffic conditions[21][25], iii) Store and Forward recovery strategy to forward packets in case of sparse road traffic[26][27]. These above mentioned modules work in close cooperation, to handle issues arising out of network fragmentation and disconnection and hence introduce reliability in the network. Extensive simulation is conducted to verify efficiency and effectiveness using NCTUns-6.0[15]-[19] which combines both traffic and network simulator. Finally the thesis is concluded by pointing out some open issues and possible direction of future research relating to routing in VANETs.

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CHAPTER 1
INTRODUCTION

1.1 Vehicular ad hoc Networks

With the sharp increase of vehicles on roads in the recent years, driving has not stopped from being more challenging and dangerous. Roads are saturated, safety distance and reasonable speeds are hardly respected, and drivers often lack enough attention. Rapid advances[8] in wireless technologies provide opportunities to utilize these technologies in support of advanced vehicle safety applications. While the major objective has clearly been to improve the overall safety of vehicular traffic, promising traffic management solutions and on-board entertainment applications are also expected to be provided.

The advanced and wide deployment of wireless communication technologies along with the increase in the number of vehicles equipped with wireless transceivers to communicate with other vehicles have resulted in growth of a special class of wireless networks, known as vehicular ad hoc networks or VANETs (Figure 1-1). Vehicular Ad hoc Network (VANET), a subclass of mobile ad hoc networks (MANETs), is a promising approach for the intelligent transportation system (ITS) and is expected to improve traffic quality and provide a more convenient driving environment for the general populace.

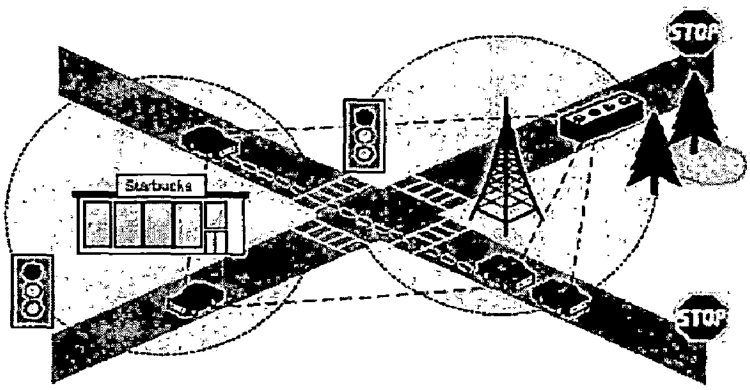

Figure 1-1: Vehicular ad hoc network (courtesy: http://monet.postech.ac.kr)

Even though VANETs is a subclass of MANETs, still most of the existing routing protocols for MANETs do not apply well to VANETs because VANETs represent a particularly challenging class of MANETs. They are distributed, self-organizing communication networks formed by moving vehicles, and are thus characterized by very high node mobility and limited degrees of freedom in mobility patterns.

1.2 Motivation

The creation of a VANET is significant to traffic management and roadside safety. Unfortunately, deployment of a service oriented VANET has its own set of challenges, the most significant of which is efficient routing under extreme traffic conditions. Since VANETs are featured by high mobility and constantly changing topology. Due to these features, VANETs are expected to experience frequent network fragmentation, resulting in a very short duration of communication. Most of previous VANET research[1][2] has focused on analyzing routing protocols to handle the broadcast storm problem in a highly dense network topology. Furthermore, the routing protocols operate under the assumption that VANET is a well-connected network. However, it has been noted that the disconnected network problem is also a crucial research challenge for developing a reliable and efficient routing protocol that can support highly diverse network topologies. To resolve the network disconnection problem, the route recovery process could be performed, but the route recovery time will result in service disruption and data loss.

So finding and maintaining routes is a very challenging task in VANETs. In addition, a realistic mobility model is very important for both design and evaluation of routing protocols in VANETs. In this dissertation the problem of reliable, efficient and fast routing in VANETs is addressed. The proposed scheme transmits data based on real time traffic and city conditions having multi-lane bidirectional roads with low end to end delay and reduced packet loss. We have efficiently used bandwidth by reducing control overhead and retransmissions due to looping.

The existing protocols choose sequence of junctions statically without taking real time traffic into consideration which would be more efficient if junctions are selected dynamically based on real time traffic data. Along with this protocol should have mechanism to handle sparse traffic condition to introduce reliability in the network which at present is handled by dropping the packet and notifying source to reinitiate entire transfer process from beginning, which is a drawback of present approach.

1.3 Problem Statement

The aim is to develop and implement an efficient multi-hop routing protocol for urban environment based on i) Multi-hop transfer of a single message by discovering the most suitable vehicle within the transmission range instead of using single hop broadcast scheme, ii) Dynamic selection of junctions using preloaded digital maps and real time traffic conditions, iii) Store and Forward recovery strategy to forward packets in case of sparse road traffic. These modules should work in close cooperation, to handle issues arising out of network fragmentation and disconnection and hence should introduce reliability in the network.

1.3.1 Problem Description

The main objective of this work is to develop and implement the routing protocol for efficient information exchange among the vehicles and propose an efficient multi-hop routing technique especially in urban scenario. This should be a more robust technique compared to traditional broadcasting technique that results in reduced packet collision and loss rate in the network. The main issues in non-broadcasting vehicular networks are route maintenance due to the need to determine the most optimum next hop based on the identification of the vehicle.

In position based routing used in city environments, every node sends it current position by a beacon message and every node knows its neighbor nodes. When a source send message to the destination it uses the geographic location of the destination. There are limitations in position based routing protocols like network disconnection, too many hops, routing loops, wrong direction. The challenges in city environment can be better understood by following example:

A source node wants to send packet to the destination. There are buildings between source and destination and there is no node closer to the destination. Two separate paths are available to the destination; one is shorter than other. But when in conventional protocols this situation occurs, they will select the route according to its right hand rule. So they will not look for shortest path, it will look for right hand rule. And packet will traverse hop-by-hop until it finds a node nearer to the destination. This takes much longer time and processing.

1.4 Organization of Dissertation

This report comprises of six chapters including this chapter that introduces the topic and states the problem. The rest of the dissertation report is organized as follows.

Chapter 2 provides a brief description of literature review on various routing protocols in VANETs. The other topics include network architecture, VANET characteristics, its applications and research gaps.

Chapter 3 gives the detailed architecture, design and working of the efficient and reliable multi-hop routing protocols for VANETs.

Chapter 4 gives the brief description of the implementation of the proposed scheme.

Chapter 5 discusses the simulation results obtained for the proposed schemes and gives a comparison with other previously available protocols.

Chapter 6 concludes the work and gives some suggestion for future work.

CHAPTER 2
LITERATURE REVIEW

Vehicular ad hoc networks (VANETs) organize and connect vehicles with one another, and sometimes with mobile and fixed location resources but due to high relative speed and dynamic information exchange are different from MANETs.

2.1 Network Architecture

The architecture of VANETs falls within following three categories (Figure 2-1)[9]:

1. **WLAN architecture:** The network uses WLAN access points to connect to the Internet and facilitate vehicular applications. Vehicles communicate with Internet by driving by a wireless access point
2. **Pure ad hoc architecture:** This is the infrastructure-less network where nodes perform vehicle-to-vehicle communication with each other.
3. **Hybrid:** This architecture include presence of roadside communication units such as an access points and vehicles equipped with wireless networking devices, so that vehicles can take advantage of infrastructure in communicating with each other.

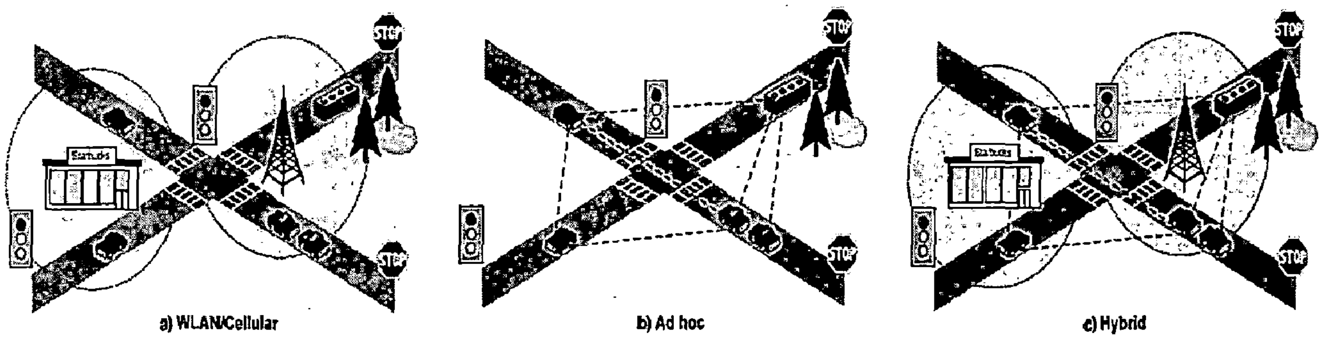

Figure 2-1: VANET Architecture [8]

2.2 VANET Characteristics

Similar to mobile ad hoc networks (MANETs), nodes in VANETs self-organize and self-manage information in a distributed fashion without a centralized authority or a server dictating the communication. Since nodes are mobile, thus data transmission is less reliable and sub-optimal. Apart from these characteristics, VANETS possess a few distinguishing characteristics mentioned below [9][11], thus presenting itself as a particular challenging class of MANETs.

1. **Highly dynamic topology**: Since vehicles are moving at high speed, the topology formed by VANETs is always changing. On highways, vehicles are moving at the speed of 60 mph (25 m/sec). Suppose the radio range between two vehicles is 250 m. Then the link between the two vehicles lasts at most 10 sec.

2. **Frequently disconnected network (Intermittent connectivity):** The highly dynamic topology results in frequently disconnected network since the link between two vehicles can quickly disappear while the two nodes are transmitting information. The problem is further exacerbated by heterogeneous node density where frequently traveled roads have more cars than non-frequently traveled roads. Moreover, non- rush hours only result in disparate node density, thus dis-connectivity. A robust routing protocol is needed for VANETs which recognizes the frequent dis-connectivity and provides an alternative link quickly to ensure uninterrupted communication.

3. **Patterned Mobility**: Vehicles follow a certain mobility pattern that is a function of the underlying roads, the traffic lights, the speed limit, traffic condition, and drivers' driving behaviors. Because of the particular mobility pattern, evaluation of VANET routing protocols only makes sense from traces obtained from the pattern. There are various VANET mobility trace generators developed for the very purpose of testing VANET routing protocols in simulation. Realistic mobility traces have been gathered from vehicles for the same purpose.

4. **Propagation Model:** In VANETs, the propagation model is usually not assumed to be free space because of the presence of buildings, trees, and other vehicles. A VANET propagation model should consider the effects of free standing objects as

well as potential interference of wireless communication from other vehicles or widely deployed personal access points.

5. **Unlimited Battery Power and Storage:** Nodes in VANETs are not subject to power and storage limitation as in sensor networks, another class of ad hoc networks where nodes are mostly static. Nodes are assumed to have ample energy and computing power. Therefore, optimizing power utilization is not as relevant as it is in sensor networks.

6. **On-board Sensors:** Nodes are assumed to be equipped with sensors to provide information useful for routing purposes. Many VANET routing protocols have assumed the availability of GPS unit from on-board Navigation system. Location information from GPS unit and speed from speedometer provides good examples for sources of information that can possibly be obtained by sensors to be utilized to enhance routing decisions.

2.3 VANET Applications

A number of unique applications are being standardized for VANETs[8][9][10]. VANET applications can be divided into following categories(Figure 2-2):

1. Public safety applications
2. Comfort applications
3. Traffic management and coordination applications
4. Traveler information support applications

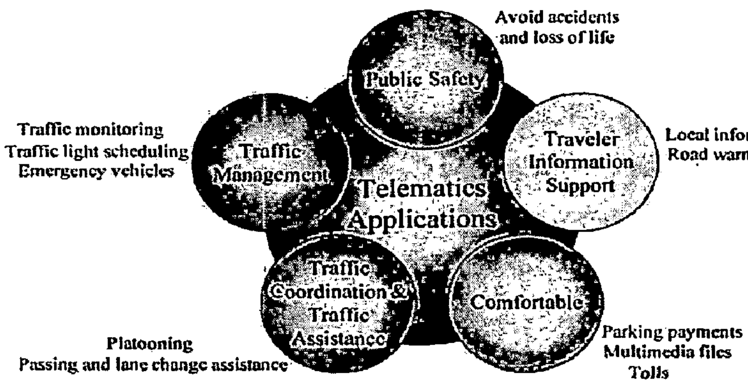

Figure 2-2: Applications in VANETs Network (courtesy: http://bbcr.uwaterloo.ca)

2.3.1 Public Safety Applications

The objective of these applications is to improve the overall safety of the transportation infrastructure. Some examples of these applications are mentioned below:

1. **Traffic Signal Violation Warning:** The goal of this application is to reduce collisions at intersections. In this scenario, a RSU is placed near an intersection that has a traffic light. Infrastructure-to-vehicle communication is used to warn approaching vehicles of the status of the traffic light and to alert drivers of a potential light violation. When a vehicle receives a traffic signal violation warning message, computation is performed on the received data to determine if the driver is at risk of inappropriately entering the intersection and if so a warning is issued to the driver.
2. **Emergency Electronic Brake Lights:** This application provides a warning to a trailing vehicle when a vehicle in front of it applies its brakes. The emergency electronic brake light application is beneficial in situations where visibility is limited, such as poor weather conditions. The data contained in braking vehicle's broadcast message is the deceleration rate and braking vehicle's location. When trailing vehicle receives the warning, an algorithm is invoked to determine the relevance of the message and whether or not the vehicle is endangered. If so, a warning is sent to the driver. The emergency electronic brake light application significantly reduces accidents by giving the driver a warning before they are able to visually sense the danger.

2.3.2 Comfort Applications

These applications increase the comfort of use by adding value-added services. But these applications have a low priority than public safety applications. This category includes the following applications:

1. **Electronic Toll Collection:** This application works by enabling driver to drive through a toll booth instead of stopping by making payment through the network.
2. **Media Applications:** These include a number of entertainment features, such as transfer of music and video files for in-car entertainment.

2.3.3 Traffic Management Applications

These applications are focused on moving traffic flow, thus reducing congestion as well as accidents resulting from congestion, and reducing travel time. Some applications that belong to this category of VANET applications are mentioned below:

1. **Traffic monitoring:** This application can provide localized timely information regarding the traffic for several vehicles around the vehicle. This application requires each vehicle to act as a sensor (determining its current speed), as a relay (if the information is to travel for more than the direct transmission range) as well as a destination (using information from the other vehicles in the system). The information can be used to simply inform the driver or, in more complex systems to suggest alternate route
2. **Traffic light scheduling:** This application aims to reduce waiting time at a traffic light intersection by dynamic scheduling of traffic lights. This system utilizes additional information (obtained using vehicle to RSU communication), such as the length of the queues at the traffic light as well as the number of vehicles expected to arrive in the near future to the efficiency of schedules.

2.3.4 Traveler Information Support Applications

These applications provide updated local information, maps, and in general messages of relevance limited in space and/or time. Some applications that belong to this category of VANET applications are mentioned below:

1. **Local information:** Information such as local updated maps, the location of gas stations, parking areas, and schedules of local museums can be downloaded from selected infrastructure places or from other "local" vehicles. Advertisements, for example, gas or hamburger prices may be sent to approaching vehicles.
2. **Road warnings:** Warnings of many types (e.g., ice, oil, or water on the road, low bridges, or bumps) may easily be deployed by authorities simply by dropping a beacon in the relevant area.

2.4 Routing in VANETs

A routing protocol governs the way that two communication entities exchange information; it includes the procedure in establishing a route, decision in forwarding, and action in maintaining the route or recovering from routing failure.

The routing protocols for VANETs can be broadly classified into three categories[9][12]:

1. **Unicast Routing protocols:** These protocols are used when message is to be sent to a static destination or a single mobile vehicle. They can be classified as:
   - Topology-based
   - Geographic (position-based).

   Complications arise when the destination is a mobile vehicle because it is more difficult to trace the location of the vehicle if it is moving.

2. **Multicast and Geocast Routing protocol:** These protocols are used when information is to be delivered to more than one location. Multicast in a VANET is defined by delivering multicast packets from a single source to all members of a multicast in a multi-hop communications. For the geocast routing, if a vehicle receives a geocast packet from neighbors, the packet should be forwarded or dropped depending on current location of vehicle. If this vehicle is located is the specific geographic region, then the geoacst packet is forwarded, otherwise, the packet is dropped.
3. **Broadcast Routing protocols:** These protocols are utilized when information is to be sent to all vehicles in the network. A source vehicle sends broadcast message to all other vehicles in the network. Broadcast is important in many applications of VANET such as advertisement publicity, group discussions and route discovery. The design issue of broadcasting is how to effectively prevent packet collision (broadcast storm problem) during the broadcasting.

In this work we dealt with unicast based routing, so from now on in the upcoming sections we will be concentrating on just unicast based routing and related unicast protocols, also all protocols discussed including proposed protocol perform multi-hop routing, this means more than one intermediate vehicle can be involved during message transfer from source to destination unlike in single hop routing where there is no intermediate vehicle.

2.4.1 Topology-Based Routing Protocols

These routing protocols use links' information that exists in the network to perform packet forwarding[9]. They can further be divided into proactive (table-driven) and reactive (on-demand) routing.

1. **Proactive (table-driven):** Proactive routing carries the distinct feature that the routing information is maintained in the background regardless of communication requests. Control packets are constantly broadcasted and flooded among nodes to maintain the paths or the link states between any pair of nodes even though some of paths are never used. A table is then constructed within a node such that each entry in the table indicates the next hop node toward a certain destination e.g. FSR [28], DSDV[30], OLSR[31], CGSR[32], WRP[33], TBRPF[34].
2. **Reactive (On demand):** Reactive routing opens a route only when it is necessary for a node to communicate with another node. It maintains only the routes that are currently in use, thereby reducing the burden on the network. Reactive routings typically have a route discovery phase where query packets are flooded into the network in search of a path. Example protocol include AODV [1], TORA[29], DSR[2], PGB[35], JARR[36].

Some important protocols with respect to mechanism involved and popularity are discussed here:

AODV (Ad Hoc On Demand Distance Vector) routing

In AODV[1], the network is silent until a connection is needed. At that point the network node that needs a connection broadcasts a request for connection. Upon receipt of a broadcast query (RREQ), nodes record the address of the node sending the query in their routing table. This procedure of recording its previous hop is called backward learning. Upon arriving at the destination, a reply packet (RREP) is then sent through the complete path obtained from backward learning to the source. At each stop of the path, the node would record its previous hop, thus establishing the forward path from the source. The flooding of query and sending of reply establish a full duplex path. A link failure will be reported recursively to the source and will in turn trigger another query-response procedure to find a new route.

DSR (Dynamic Source Routing)

Dynamic Source Routing (DSR)[2] uses source routing, that is, the source indicates in a data packet's the sequence of intermediate nodes on the routing path. In DSR, the query packet copies in its header the IDs of the intermediate nodes that it has traversed. The destination then retrieves the entire path from the query packet, and uses it to respond to the source. As a result, the source can establish a path to the destination. If we allow the destination to send multiple route replies, the source node may receive and store multiple routes from the destination. An alternative route can be used when some link in the current route breaks. In a network with low mobility, this is advantageous over AODV since the alternative route can be tried before DSR initiates another flood for route discovery. There are two major differences between AODV and DSR. The first is that in AODV data packets carry the destination address, whereas in DSR, data packets carry the full routing information. This means that DSR has potentially more routing overheads than AODV. Furthermore, as the network diameter increases, the amount of overhead in the data packet will continue to increase. The second difference is that in AODV, route reply packets carry the destination address and the sequence number, whereas, in DSR, route reply packets carry the address of each node along the route.

2.4.2 Position-Based Routing Protocols in VANETs

In geographic (position-based) routing, the forwarding decision by a node is primarily made based on the position of a packet's destination and the position of the node's one-hop neighbors [8][9][12]. The position of the destination is stored in the header of the packet by the source. The position of the node's one-hop neighbors is obtained by the beacons sent periodically with random jitter to prevent collision. Geographic routing assumes each node knows its location, and the sending node knows the receiving node's location by use of GPS unit. Since these protocols do not exchange link state information and do not maintain established routes like topology-based routings do, they are more robust and promising in the highly dynamic environments like VANETs. Geographic routing can be classified into two categories:

1. **Non-Delay Tolerant Network (non-DTN) Protocols:** These protocols do not consider intermittent connectivity and are only practical in densely populated VANETs. This group of protocols includes Greedy Perimeter Stateless Routing (GPSR)[3], Connectivity Aware Routing (CAR)[6], A-STAR[14], GPSRJ+[13], STBR[37], LOUVRE[38].
2. **Delay Tolerant Network (DTN) Protocols:** These protocols consider dis-connectivity and are designed from the perspective that networks are disconnected by default. This group of protocols includes Fastest-Vehicle multi-hop routing protocol[20], Vehicle Assisted Data Delivery (VADD)[7], Geographical Opportunistic Routing (GeOpps)[4] etc.

Some important protocols with respect to mechanism involved and popularity are discussed here.

Fastest-Vehicle Multi-hop Routing Protocol

Fastest-vehicle multi-hop routing (FMR)[20] protocol for vehicular ad-hoc network is based on speed information of each vehicle used for message transfer and distance of the selected vehicle from the destination vehicle. On the basis of speed of the vehicles and distance of the vehicles from the destination, the time for each vehicle within the transmission range is calculated. The vehicle with the least time is selected as the next hop for data dissemination. Instead of using request broadcast strategy at every hop while transferring the message, only a few hops with the highest speed and shortest distance from the destination vehicle among other neighboring vehicles are chosen to transfer the message. The vehicle selection in the fastest multi-hop routing is based on the velocity of that vehicle and the distance of that vehicle from destination. With the help of a navigation system (GPS), the location of every vehicle within the transmission range can be traced which provides the distance between vehicles. The distance and speed of a vehicle is traced within a specified transmission range of the vehicle which requests for message transmission. Once the next hop vehicle is selected, the next task is to transfer the message to the next hop vehicle. The source vehicle tries to send the message to next hop vehicle with the shortest time, and receives the acknowledgment from that next hop vehicle. Once the next hop vehicle of with the shortest transfer time receives the message, it performs the same task of finding the next hop vehicle with the shortest transfer time, and transferred the message to next hop vehicle. While looking for next hop vehicles within the transmission range, if the neighbor finds the destination vehicle in its range it sends the final message to the destination and discards the procedure of finding the next hop vehicles in the network. The route is created hop by hop in this process for the purpose of sending back the acknowledgment from the destination to the source vehicle.

GPSR (Greedy Perimeter Stateless Routing)

In Greedy Perimeter Stateless Routing (GPSR) (Karp, 2000)[3], a node forwards a packet to an immediate neighbor which is geographically closer to the destination node. This mode of forwarding is termed greedy mode. When a packet reaches a local maximum, a recovery mode is used to forward a packet to a node that is closer to the destination than the node where the packet encountered the local maximum. The packet resumes forwarding in greedy mode when it reaches a node whose distance to the destination is closer than the node at the local maximum to the destination. GPSR recovers from a local maximum using perimeter mode based on the right-hand rule.

CAR (Connectivity-Aware Routing)

CAR[6] uses AODV-based path discovery to find routes with limited broadcast from PGB. However, nodes that form the route record neither their previous node from backward learning nor their previous node that forwards the path reply packet from the destination. Rather, anchor points, which are nodes near a crossing or road curve, are recorded in the path discovery packet. A node determines itself as an anchor point if its velocity vector is not parallel to the velocity vector of the previous node in the packet. The destination might receive multiple path discovery packets; it chooses the path that provides better connectivity and lower delays. AGF is then used to forward the route reply back to the source via the recorded anchor points. In addition to handle mobility by AGF, CAR introduces "guards" to help to tack the current position of a destination. A guarding node can filter or redirect packets or adds information to a packet that will eventually deliver this information to the packet's destination.

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

In A-STAR[14] packets are routed through anchor points of the overlay. However, A-STAR is traffic aware: the traffic on the road determines whether the anchor points of the road will be considered in the shortest path. A-STAR routes based on two kinds of overlaid maps: a statically rated map and a dynamically rated map. A statistically rated map is a graph that displays bus routes that typically imply stable amount of traffic. Dijkstra paths computed over the statistically rated map are in general connected because of the extra knowledge. A dynamically rated map is a map that is generated based on the real-time traffic condition on the roads. Thus, the difference between a statically rated map and a dynamically rated map is accuracy of road traffic; while a statically rated map is based on bus routes that typically have high traffic volume, a dynamically rated map is based on the traffic monitored dynamically by road-side units. A-STAR also proposes a different recovery algorithm when the packet gets stuck due to dis-connectivity of the current path to the destination. The node will recompute a new anchor path and the road segment where the packet is currently located will be marked as "out of service" temporarily to prevent other packets from entering into the same problem. The notification of "out of service" is piggybacked in the recovered packets. Nodes that receive the recovered packets update their map and recomputed anchor paths accordingly.

VADD (Vehicle Assisted Data Delivery)

VADD[7] is a vehicular routing strategy aimed at improving routing in disconnected vehicular networks by the idea of carry-and-forward based on the use of predictable vehicle mobility. A vehicle makes a decision at a junction and selects the next forwarding path with the smallest packet delivery delay. A path is simply a branched road from an intersection. The expected packet delivery delay of a path can be modeled and expressed by parameters such as road density, average vehicle velocity, and the road distance. The minimum delay can be solved by a set of linear system equations.

2.5 Research Gaps

The following research gaps were identified after critical literature review.

1) Lack of min-delay unicast routing approach under low network density. The impact of intense density variability should be incorporated into the protocol design.[26][27]
2) Lack of reliability in unicast routing protocols to simultaneously reduce delivery delay time and the number of packet retransmissions.[20][21][23][25]
3) Scalability issues exist in existing VANET routing protocols for metropolitan cities.[22]
4) No existing protocols take into account driver's behavior and patterned mobility.[9]

In the proposed work the three modules as mentioned in section 1.3 collectively handle first three research gaps. Whereas fourth research gap is more of a data analysis problem than network routing issue so is not included in this work.

CHAPTER 3
PROPOSED SCHEME FOR MULTI-HOP ROUTING IN VANETs

This chapter gives the complete architecture, design and working of the Efficient and Reliable Multi-hop routing protocol for VANETs in detail which tries to fulfill the requirements needed for reliable and fast connectivity in urban environment.

3.1 System Assumptions

We assume vehicles communicate with each other through short range wireless channel (100m-250m)[13][14][20], and vehicles can find their neighbors through beacon messages. Furthermore apart from neighboring node location, sending node also needs position of destination which is provided by some infrastructural service. The packet delivery information such as source id, source location, packet generation time, destination location, expiration time, etc., are specified by the data source and placed in the packet header. A vehicle knows its location by triangulation or through GPS device, which is already popular in new cars and will be common in the future. We assume that vehicles are equipped with pre-loaded digital maps, which provide street-level map and traffic statistics such as traffic density and vehicle speed on roads at different times of the day. Such kind of digital map has already been commercialized. Also it is assumed that route is created hop by hop and assumed to be active till the destination receives the messages and send the ACK back.

3.2 Proposed Protocol

To carry out vehicle to vehicle communication for successful and efficient communication requires reduced overheads and resource consumption within the network. Therefore to meet our requirements here we are extending Fastest Vehicle Multi-hop routing(FMR) protocol[20], by making it more robust for urban scenario by handling the specific needs especially of city and developed region (vehicle distribution, interruption of signal by buildings, highly mobile and dynamic topology etc.) Present Fastest Vehicle Multi-hop routing protocol[20] performs well for highway scenarios but fails to perform well in urban environment where there are lot of junctions and intersections, variable traffic mobility due to traffic signals and jams.

In this proposal I provide solution to the above problem by extending the above mentioned protocol by incorporating following modules (Figure 3-1): i) Multi-hop transfer of a single message by discovering the most suitable vehicle within the transmission range (base protocol), ii) Dynamic selection of junctions using preloaded digital maps and real time traffic conditions, iii) Store and Forward recovery strategy to forward packets in case of sparse road traffic. The base FMR protocol choose sequence of junctions statically without taking real time traffic into consideration which would be more efficient if junctions are selected dynamically based on real time traffic data and is handled by module ii as mentioned above. Similarly module iii adds mechanism in the proposed protocol to handle sparse traffic condition and thus introduce reliability in the network which at present is not handled in the base protocol and such condition is encountered by dropping the packet and notifying source to reinitiate entire transfer process from beginning, which is a drawback of FMR protocol.

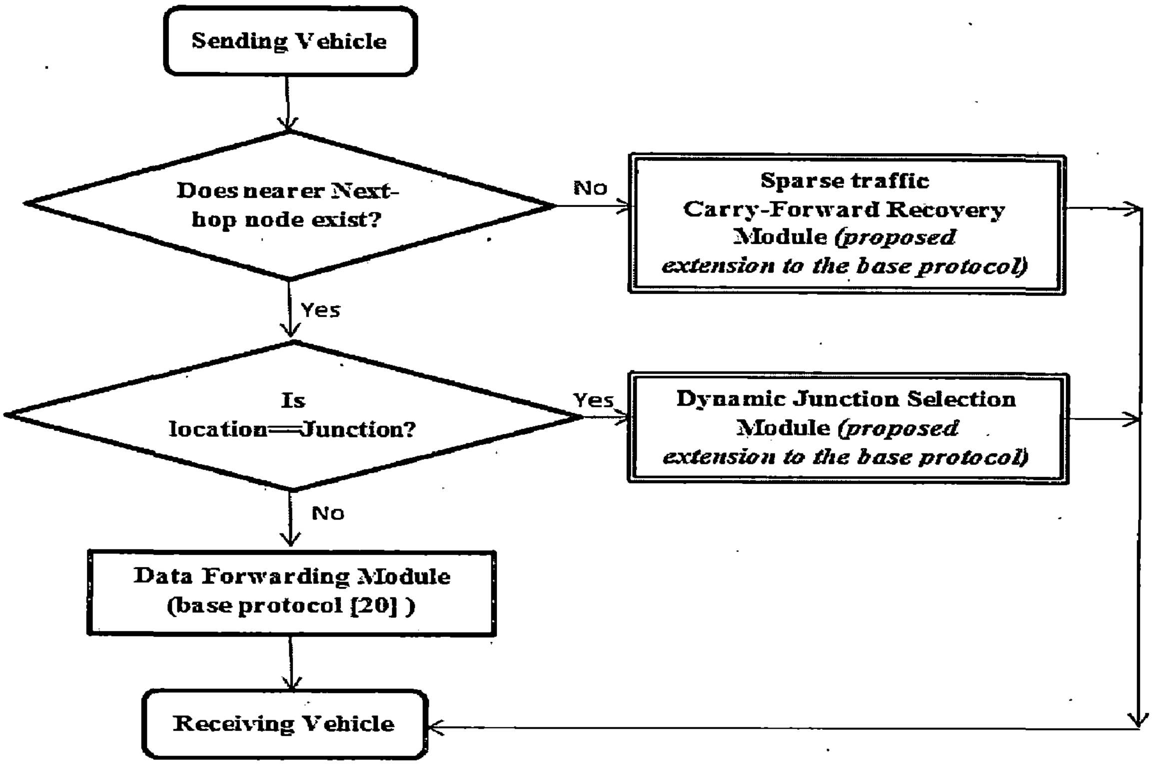

Figure 3-1: Architecture of proposed Efficient & Reliable Multi-hop Routing (ERMR) protocol

3.2.1 Data Forwarding Module

This module [20] works on two variables, one is speed of the vehicle(node) involved in message transfer and other is distance of the selected vehicle from the destination, by these the time of message transfer for each vehicle within the transmission range is calculated and the vehicle with the minimum time is selected as the next hop for data dissemination. In this proposed protocol in place of using request broadcast at every node while data transfer; only top two nodes with the highest speed and shortest distance are selected for data transfer. Thus in order to confirm the number of neighboring vehicles within the transmission range beaconing is performed every time when a message is transferred from one hop to another hop. Thus vehicles send periodical Hello messages (or beacons) to the next possible hops and then waiting for return ACK packets.

These hello messages (Figure 3-2) are sent in order to maintain updated information about their neighboring nodes enabling successful message transfer. If path breaks, the previous node to the node where communication failure took place restarts beaconing to rebuild the path by finding another suitable node within the range and this route is forwarded to the hops until the destination vehicle is reached.

HELLO
Source IP
Source Location
Source Speed
Source Direction
Neighbor List: IDs and location
Forwarding options

Figure 3-2: Hello packets transmitted for gathering neighboring hop information

Therefore for successful route recovery nodes should inform their previous node about its next hop node so that if path breaks nodes has information of its two hop distant node in order to recover and maintain the route.

Vehicle Selection

In this routing mechanism is based on distance of the node (vehicle) from the destination and the velocity of that vehicle. With help of GPS or any other infrastructural service we can find the distance between two desired nodes. Source node requests for all neighboring nodes in its transmission range by broadcasting hello request, and the receiving node sends back acknowledgement to the requesting node with its current location and velocity. Once location and velocity are known by the requesting node it calculates the time taken by each node to reach the destination using equation (3.1):

$$\mathbf{T_{Ni} = S_{Ni}/V_{Ni}} \tag{3.1}$$

(Where TNi, SNi and VNi are time taken by the neighboring node i to reach destination, curve metric distance between neighboring node i, and destination, and current speed of the neighboring node.)

To reduce overhead information of all other nodes except the two nodes that takes least time is discarded and message is transferred to the node with the shortest carrying time. Top two nodes are chosen to add redundancy and act as failover so that to prevent entire transfer process to restart from very beginning in case first node fails to deliver the packet. In this whole process of identifying neighboring nodes, source or intermediate node check neighboring nodes in range for their direction of motion. It only considers nodes moving in direction of destination node and discards other nodes which are travelling in opposite direction. This direction aware approach makes route maintenance between source and sink of data transfer, a lot easier and long lived.

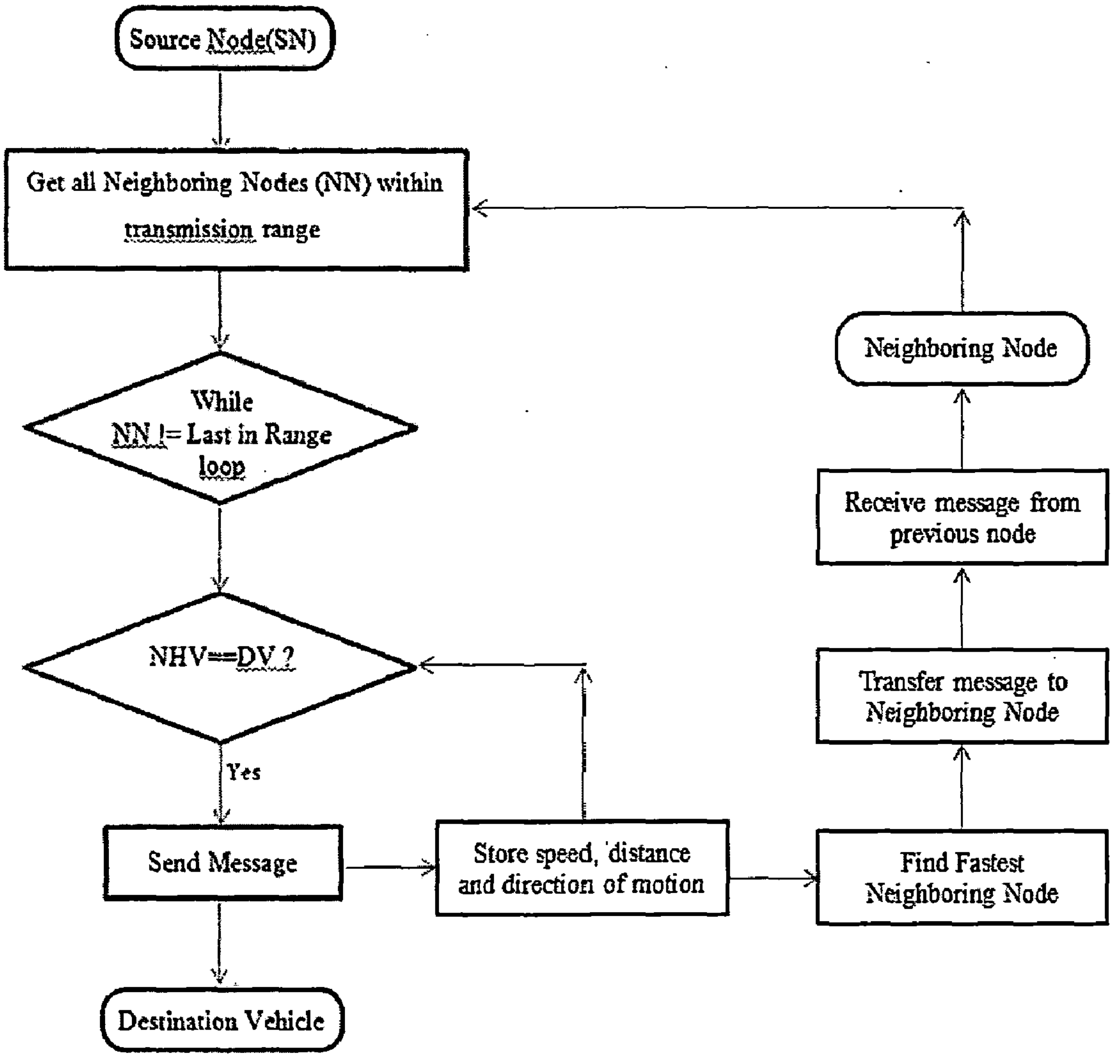

Figure 3-3: Fastest-Vehicle multi hop data forwarding algorithm[20]

This direction matching is one of the most significant step which prevents looping and help routing packet on the correct shortest path to the destination. The algorithm to select the most suitable neighboring node is repeated recursively starting from source node then by intermediate node until the destination is found. The destination node after receiving the packet sends an acknowledgement back to the source by the established route.

Next Hop Vehicle Communication

After selection of next-hop neighboring node, the next task is to transfer data to the next-hop neighboring node. Source node sends message to the next-hop neighboring node with the shortest time *Ts,* and receives the acknowledgement from that neighboring node. Once the neighboring node with shortest time receives the message it again performs the same task of finding its next-hop neighbor with shortest time and transfers the message to that node. If in this process source/intermediate node finds the destination node in range it aborts the search and delivers the message to the destination node and acknowledgement is send by the destination to the source hop by hop.

In Figure 3-3 the flowchart [20] shows the fastest-vehicle multi-hop routing algorithm used in this data forwarding module. The flowchart starts with source node querying neighboring nodes within transmission range for their velocity and location. Flowchart depicts the recursive process of transferring the message until the destination node sends an ACK packet through the route to the source node.

3.2.2 Junction Selection Module

Like most of the position-based routing protocol our proposed Efficient and Reliable Multi-hop Routing (ERMR) protocol is a street aware, anchor based routing protocol with which unlike GSR computes anchor path with traffic(in this context: vehicular traffic) awareness and unlike GSR, A-STAR and many other protocols where intermediate junction sequence are sequentially but statically chosen, this ERMR protocol choses intermediate junctions dynamically[21][25] and in order to be traversed considering traffic condition and curve metric distance to the destination node. This dynamic junction selection approach has following advantages:

i. The packet header size is fixed as next anchor point or junction is computed on the fly.
ii. The computation of anchor points is more accurate as latest vehicular traffic statistics are being used.
iii. Subsequent anchors can be computed more accurately as most updated information of the location of the destination is being used instead of using old information captured at source node which gets change with time.

In order to select subsequent junction the node (which may be source, intermediate or destination node) finds the neighboring junction using preloaded-digital maps. Then priority order is assigned to each junction on the basis of number of vehicles moving in the direction of destination, curve metric distance to the destination and variation of the vehicular traffic density. The final candidate junction to be selected is one having highest priority order and is closest to the destination vehicle and have highest vehicular density moving in the direction of destination with least variation in the distribution of the vehicles on the road between the current and next-chosen junction. In Figure 3-4 we have shown a scenario, where vehicle S after receiving data packet computes priority order of each neighboring junction. Taking into account the variation of vehicle distribution on road in direction of destination, their number and curve metric distance to the destination selects intersection I2, and is used as next anchor point.

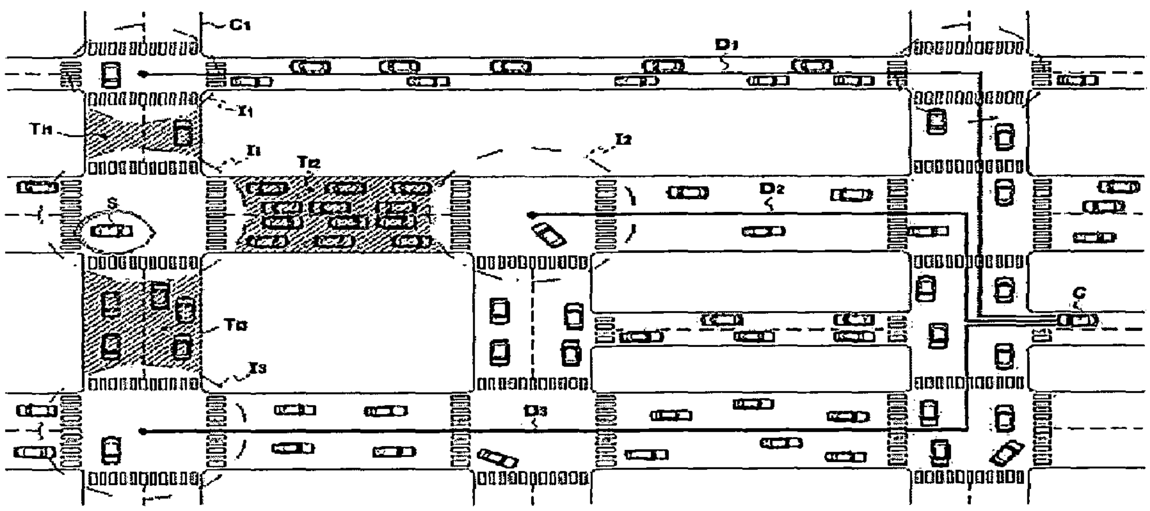

Figure 3-4: Junction selection mechanism [25]

Due to this real-time traffic-aware approach the route established are reliable with higher connectivity. To calculate priority order we have used algorithm mentioned below:

Pseudo Code:

1. LET I= Current Intersection
2. FOR (all candidate intersections 'J')
3. D_J = the curve metric distance between J and destination node.
4. D_I = the curve metric distance between I and destination node.
5. D_C = D_J/D_I. (DC calculates closeness of J to the destination node)
6. N_i = number of vehicles within cell *i* travelling in direction of destination.
7. N_c = number of cells between I and J.

8. N_{avg} = average number of vehicles per cell travelling in the direction of the destination as shown in equation (3.2).

$$N_{avg} = \frac{1}{N_c}\sum_{i=1}^{N_c} N_i \tag{3.2}$$

9. σ = standard deviation of cell density Ni as shown in equation (3.3).

$$\sigma = \sqrt{\left(\frac{1}{N_c}\left(\sum_{i=1}^{N_c}\left(N_i - N_{avg}\right)^2\right)\right)} \tag{3.3}$$

10. $\alpha + \beta = 1$ (weights assigned to distance and traffic density parameters)
11. Priority Order for junction J (P_J) as shown in equation (3.4).

$$P_J = \alpha \times [1 - D_C] + \frac{\beta}{\delta} \times \left[\frac{N_{avg}}{1+\sigma} \right] \tag{3.4}$$

Greater the value of P_J more is its priority. From above we can see that priority order is determined by two factors:

a) The first factor is the measure of closeness of junction to the destination. Shorter distances are preferred therefore, to calculate priority order we used the factor [1-D_c], where D_c is the closeness of the candidate junction J to the destination. Hence more closer the junction is to the destination lower will be the factor D_c and greater will be the priority order (P_J). If Dc=0 which means destination vehicle is at candidate junction then [1-D_c]=1 which is the highest value possible and if candidate junction is farther away as compared to current junction, then [1-D_c] < 0 which will further reduce the value of priority order for that junction. Therefore D_c has an significant role by representing junction at shortest 'curve metric' distance from the destination.
b) The second factor is the measure of traffic density of vehicles moving in the direction of destination between current junction I and candidate junction J.

Thus balanced street with higher traffic densities are preferred. It depends on following parameters: N_{avg} (average number of vehicles per cell moving in direction of destination) and σ (the standard deviation of cell density) and δ=20 (an experimentally derived constant that represents ideal connectivity degree within a cell) in order to bring the value of whole factor down to less than 1. We have used factor of $1/(1 + \sigma)$ in order to reduce the priority order of streets having high standard deviation which occurs when vehicles are not uniformly distributed on road may be are in form of clusters causing gaps.

Traffic Density Estimation

To estimate traffic density we have used a decentralized approach as discussed in [25]. The decentralized approach is based on the traffic information exchanged among vehicles that are arranged into location based groups. In order to achieve this roads are divided logically into small fixed area called cells, each defining a group. Size of cell is determined by transmission range of the node (250m approximately), and a unique identity is given to each cell based on coordinates of the cell. The small area around the cell center as shown in figure is from where vehicle is elected as a group leader by selecting a vehicle closest to the cell center. Local density information is then estimated by each group leader and transmitted among groups using Cell Density Packets. When group leaders reach a road intersection they generate a new CDP before leaving the road.

3.2.3 Store-Carry-Forward Recovery Module

Store-Carry-Forward module is designed for sparse density ad hoc networks. In this mechanism each node stores data packets, it carries data packets if there are no nodes within the transmission range, and then, when it encounters the other node, it forwards the duplicated data packets to all of them. This mechanism is very inefficient due to epidemic routing; therefore we follow the mechanism as discussed in [26] and [27]. In this approach epidemic routing combined with the position information and moving direction of node obtained from Global Positioning System. Thus reducing the duplicate data packets in the network. In place of forwarding duplicate packets to each node that comes in vicinity, in this approach when a transmitting node *i* forwards duplicated data packets to neighboring node *j* taking into account the position and location information of transmitting and receiving nodes.

Condition 1: The position of neighboring node *j* is nearer to destination than that of transmitting node *i;*

Condition 2: Neighboring node *j* moves toward the direction of destination node.

Transmitting node *i* forward the duplicate packet to the neighboring node *j* which satisfies both the above condition. For Condition-1 curve metric distance is used while for evaluating Condition-2 angle threshold is used. In Figure 3-5 and Figure 3-6 [26] there are three nodes A, B, C within range of node S, which stores data packets.

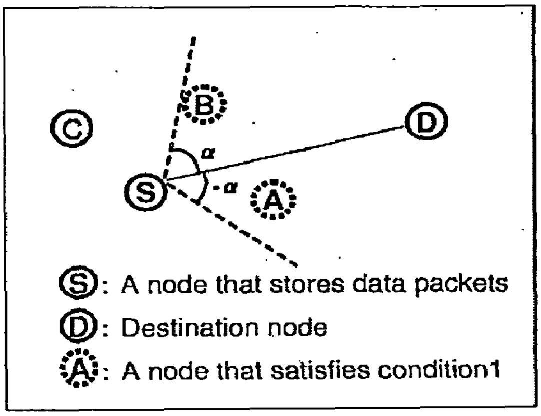

Figure 3-5: Example of Condition 1

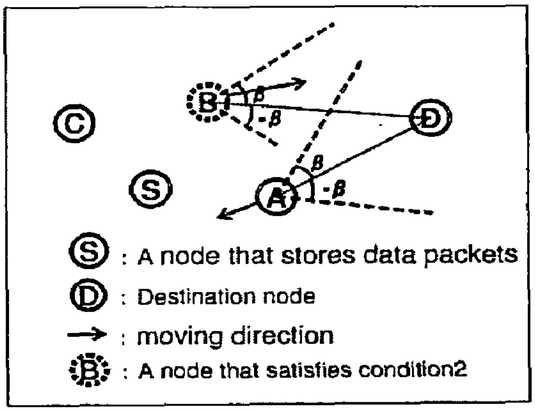

Figure 3-6: Example of Condition 2

In order to define whether the neighboring node is moving in the direction of destination or not, angle threshold α (here ± 90°) is decided by node S, and if neighboring node lies in between angle α on both sides of line joining S are selected and then these selected node define another threshold β (here ±45°) , and all the nodes moving in the direction covered by this area which expands on both the side of line joining that particular neighboring node and destination are finally considered to be satisfying condition-1 and are further tested to satisfy condition-2. Thus in the above figures node A only satisfies both Condition-1 in Figure 3-5 and node B only satisfies Condition-2 in Figure 3-6.

CHAPTER 4 IMPLEMENTATION DETAILS

The simulation of the proposed scheme was done using NCTUns (National Chiao Tung University network simulator)[15][16][17][18][19]. NCTUns is specially designed for VANET simulation with built-in microscopic mobility model, traffic simulator and the ability to generate a city map complete with intersections and traffic signals.

4.1 Introduction to NCTUns

VANET simulation requires that a traffic and network simulator should be jointly used with a powerful feedback between them to render the simulation results as accurate as real life. We first presented features of important traffic and network simulators and also certain VANET simulators. We presented various possibilities for combining the two and these possibilities are as follows:

- Separate Traffic and Network simulator: VanetMobiSim and NS-2.
  Problem: Traces are generated once and therefore no feedback is allowed.
- Integrating Traffic and Network simulator: TraNs
  Problem: Loose coupling, the feedback process is slow.
- Federating Traffic and Network simulator: MOVE and NS-2 / QualNet
  Problem: Still lack interaction.

NCTUns is a high-fidelity network simulator and emulator. By using a novel kernel re-entering simulation methodology, it provides many unique advantages over traditional network simulators and emulators. It can simulate many different types of networks. NCTUns incorporates traffic simulation (e.g., road network construction and microscopic vehicle mobility models) with its existing network simulation, tightly integrates them together, and provides a fast feedback loop between them. As such, now NCTUns is a useful simulation platform for wireless vehicular ad hoc network research. There are four major components existing in NCTUns: Graphical User Interface (GUI), Simulation Engine (SE), Car Agent (CA), and Signal Agent (SA).

After careful study and rigorous analysis within the limit of available resources NCTUns was selected to be used as simulator for this work for following reasons:

- **High-Fidelity Simulation Results:** NCTUns directly uses the real-life Linux's TCP/IP protocol stack to generate high-fidelity simulation results.
- **It can run any real-life UNIX application program on a simulated node without any modification.** Any real-life program (e.g., P2P BitTorrent or Java programs) can be run on a simulated host, router, mobile node, etc. to generate realistic network traffic. This capability also enables a researcher to evaluate the functionality and performance of a distributed application or system under various network conditions.
- **It can be easily used as an emulator:** An external host in the real world can exchange packets (e.g., set up a TCP connection) with nodes (e.g., host, router, or mobile station) in a network simulated by NCTUns.
- **It supports distributed emulation of a large network over multiple machines:** The emulated network has many nodes, and many real-world applications can run on these nodes, many real-world devices can connect to it emulated network, or a single machine may not have enough CPU power and main memory to run the emulation in real time. In such a condition, NCTUns can partition the emulated network into several smaller parts and let each part be emulated by a NCTUns machine.
- **It supports seamless integration of emulation and simulation.** A complicated network simulated by NCTUns can be seamlessly integrated with a real-life network.
- **It can use any real-life UNIX network configuration and monitoring tools:** For example, the UNIX route, ifconfig, netstat, tcpdump, traceroute commands can be run on a simulated network to configure or monitor the simulated network.
- **Its setup and usage of a simulated network and application programs are exactly the same as those used in real-life IP networks.**
- **It simulates various important networks.** The supported networks include Ethernet-based fixed Internet, IEEE 802.11(b) wireless LANs, mobile ad hoc (sensor) networks, GPRS cellular networks, optical networks (including both

circuit-switching and busrt-switching networks) and many other type of wireless networks etc.

- **It generates repeatable simulation results.** If the user fixes the random number seed for a simulation case, the simulation results of a case are the same across different simulation runs even if there are some other activities (e.g., disk I/O) occurring on the simulation machine.
- **It provides a highly-integrated and professional GUI environment.** This GUI can help a user to quickly (1) draw network topologies, (2) configure the protocol modules used inside a node, (3) specify the moving paths of mobile nodes, (4) plot network performance graphs, (5) play back the animation of a logged packet transfer trace, etc. All of these operations can be easily, intuitively, and quickly done with the GUI.
- **Its simulation engine adopts an open-system architecture and is open source.**
- **It supports remote and concurrent simulations.** NCTUns adopts a distributed architecture. The GUI and simulation engine are separately implemented and use the client-server model to communicate. Therefore, a remote user using the GUI program can remotely submit his (her) simulation job to a server running the simulation engine. This can increase the total simulation throughput.

4.2 Mobility Model

The mobility model used in the simulation has a great impact on the protocol's behavior and simulation results. We have used an improved adaptation of mobility model used in [fastest vehicle] to simulate the movement pattern of moving vehicles on streets or road defined by maps from GPS equipped in vehicles.

- We have used realistic road network by using road layout of IIT Roorkee and surrounding area scaled up to an appropriate size. In this model we have road comprising of two or more lanes.
- Vehicles or nodes are randomly distributed with linear node density according to city map constraints and structure.

- Each vehicle can move with different speed, and in two directions i.e. up/down the road depending on the vehicle itself.
- In cross roads, vehicles select desired direction based on the random probability assigned to each road turn this leads to uneven traffic density on roads.
- A safe distance is maintained between two subsequent vehicles in a lane. Vehicles simulated by NCTUns can overtake the preceding vehicle.
- Packet transmission is possible and can be done by vehicles moving in both directions depending upon the routing protocol working on the node. In this mobility model message transmission is deterministic and instantaneous within set defined transmission range of 250m radius where message can be delivered by certainty but is unavailable further away.
- Vehicles have unicasting, multicasting and broadcasting capability to the neighboring vehicles inside transmission range.

4.3 Simulation Setup

The simulations were carried out using NCTUns 6.0. The vehicular movement pattern generation is based on a 3000 x 2000 m^2 rectangle street area of IIT Roorkee and surrounding scaled up to before mentioned size, consisting of 26 intersections and 38 two way roads as shown in Figure 4-1. Vehicles are randomly placed on roads which chooses to move in any direction i.e. towards one of the two intersection randomly with the average speed between 8m/s (28.8 kmph) to 50m/s (180kmph) depending on vehicle type. Each vehicle uses 802.11b with channel capacity of 11Mbps.

The simulation results are averaged over twelve runs. Simulation time of each run is of 150sec. Nodes transmit new packets at rate of 1 to 10 packet per second. The weighing factor α and β are set to 0.5 both[25]. The distance between source and destination vehicle is 1490m (1.49 km) approximately. Number of vehicles range from 50 to 250.

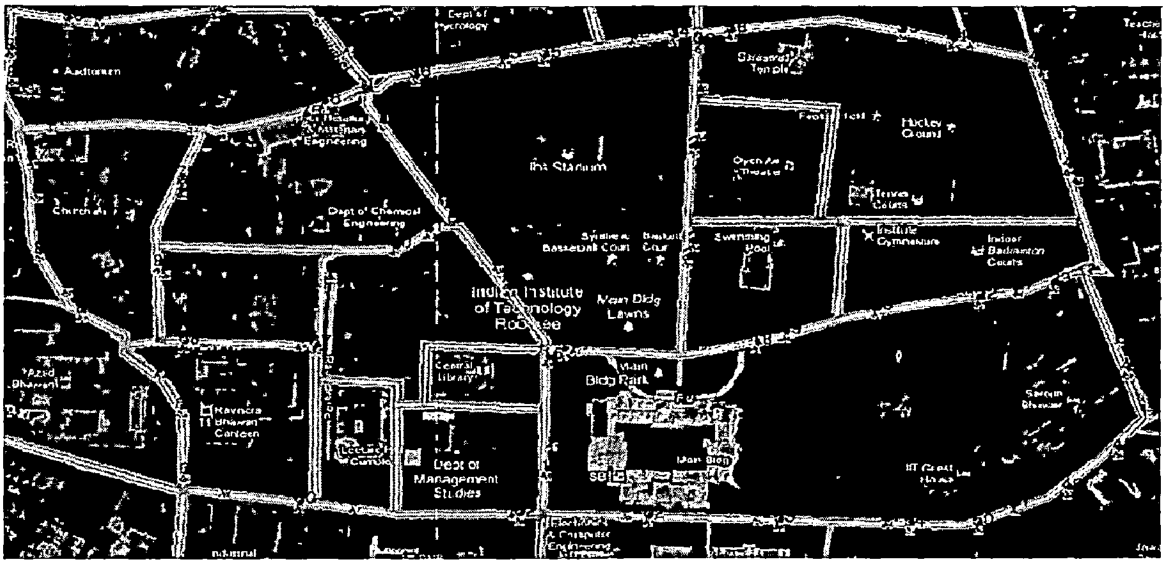

Figure 4-1: IIT Roorkee road layout used for testing this protocol

4.4 Car Agent

Car Agent application is responsible for controlling vehicle's associated movement and behavior. According to surrounding traffic and road condition a Car Agent running on vehicle makes its moving decision dynamically, which in our simulation also interacts with simulator's GUI to update and control its movement. Its agent logic which obtains the direction of road ahead, and obtains the information of neighboring lanes so that vehicle can safely change lanes, overtake other vehicles and to make turn smoothly. Car Agent communicates with other components of the simulator to deliver information about itself and fetch information about its surrounding traffic and environment. Architecture of Car Agent is shown in Figure 4-2.

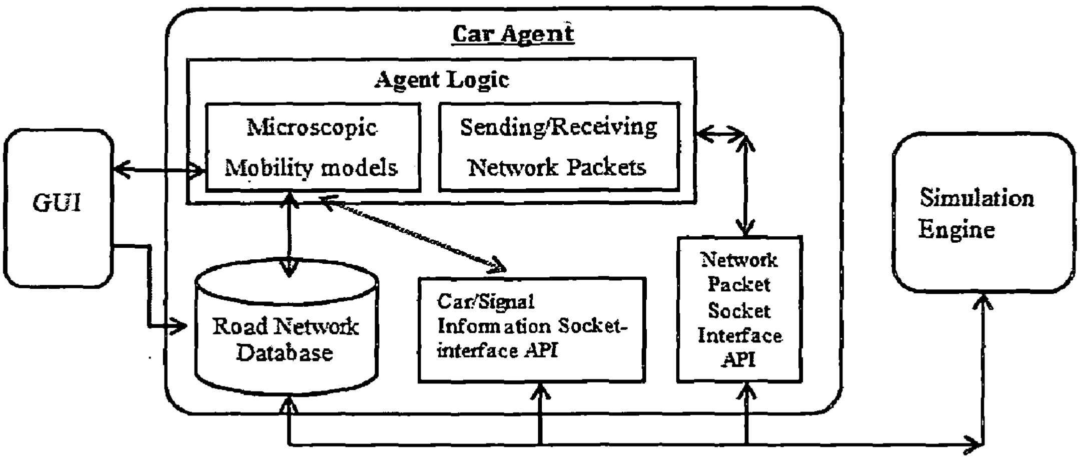

Figure 4-2: Car Agent Architecture

Car Profile Setting

A car profile defines the vehicular movement characteristics, like vehicle's maximum speed, maximum acceleration, and maximum deceleration (Profile data is given in next chapter).

Network Protocol Stack

As we know vehicles can be loaded with several types of wireless radios which require different type of protocol stack, also agents running on the node require different protocols at different layers therefore each protocol has been implemented into separate module so that any changes made at one layer do not effects protocols running at other layers.

4.4.1 Car Agent Implementation

Car Agent in the simulation setup which consist of following functions. Most of these are abstract interface provided by NCTUns whose implementation has to be done by the developer according to the requirements of the protocol.

- ***void MyAlgorithm()***

  This is the most important module of the implementation. It is the main function in which major functionality of all the three sub modules of this protocol are implemented. It is this module which decides which intersection to choose, to which node packet has to be transferred in case of sparse traffic condition or during greedy forwarding etc.
- ***void reportMyStatusToAGroupOfNode()***

  This is the interface provided by NCTUns. This function updates nodes in range with details of its speed, direction, location etc. whenever it receives request packets from neighbors. Default implementation as provided by the simulator is used.
- ***void SendBroadMessage()***

  This method is used to send broadcast messages over the wireless network.
- ***void SendFirstMessage(int)***

  This network layer module is used to transfer message from source node to next hop which may be destination.

- ***void SendFinalMessage(int)***

  This network layer module is used to transfer message to destination node from current node which may be source node.

- ***void SendNHVMessage()***

  This network layer module is used to transfer message to next hop vehicle by taking just node id as input from application layer send function here invoking node is not the source.

- ***void init()***

  This module initializes all car nodes according to the profile assigned to them by the simulator, initializes their current location, velocity and acceleration. It transfers statistics like road width and other driving conditions from simulator database to nodes database.

- ***int ReachTheNextTriggerPointOrNot()***

  This module returns invoking node whether at its current position any event is scheduled or not. Implementation provided by the simulator has been used.

- ***bool getNodesWithinRange()***

  This module tells the invoking node which nodes are in its range.

- ***void FillTheQueue(int, double*, double*, double*, double, double, double)***

  This module fills the queue when agent just has reached a new road block with the events that can place take place according to the turn taken by the vehicle (node). Implementation as provided by simulator has been used.

- ***void DetermineVelocity(double&, double&) and double DetermineAcceleration()***

  This is an important module controls nodes velocity and acceleration respectively according to the conditions on the road like vehicle is approaching, events like road block by broken car, approaching traffic light or there is some other vehicle in its lane etc.

- ***void ReceiveMessage()***

  This module responsible for listening and capturing all packets destined for that node.

CHAPTER 5
RESULTS AND DISCUSSION

The following sections discuss the performance of the proposed protocol.

5.1 Simulation Parameters

The simulator used is NCTUns [15-19] (National Chiao Tung University network simulator), a simulator designed for VANET simulations. The simulation parameters are standards representing city scenario and used in most of the literature [6][7][13][14][20][21][23].

Table 5-1
Simulation Configuration

Simulation Scenario	City Environment
City Simulation Area	3000m x 2000m
Communication Range	200m
Simulation runtime	150 sec - 200 sec*
Transmission Power	15 dbm
Channel Bandwidth	11Mbps
Average Building height	10m
Average Building distance	80m
Street Width	40m
Antenna Height	1.5m
Total simulation runs for each protocol	12

**Note: Assumption of minimum simulation time of 150 sec, apart from being assumed in other literature for VANETs, is also validated for the given scenario by the fact that time required for each packet is $6.6x10^{-5}$ sec in worst case scenario when packet is transferred through each and every node i.e. On average 82 nodes in the network to reach destination. Using this statistics $23x10^{5}$ packets will be transferred in given simulation time of 150 sec. Even Permissible latency for VOIP traffic is 300ms as compared to achieved latency of .066ms thus assumption of 150 sec is quite valid assumption as adequate amount of traffic is generated to test the scenario. [6][7][14][20][21][23]*

Table 5-2
Vehicle Profiles

Vehicle Profile	Maximum Speed (m/s)	Maximum Acceleration (m/s^2)	Maximum Deceleration (m/s^2)
Profile 1	8	3.0	1.0
Profile 2	18	2.2	4.0
Profile 3	36	3.0	5.0
Profile 4	20	10.0	3.0
Profile 5	50	15.0	20.0

5.2 Performance Metrics Used

The performance metrics considered are number of packet collision, number of dropped packets, channel/bandwidth consumption, and packet delivery ratio.

5.2.1 Packet Collision

The protocol performance is measured in terms of packet collision at source and destination as these two are the extremes end points where there is the most probability of packet collision because at source and destination packet density would be maximum due to single point of divergence and convergence of packet routes with all nodes transmitting at almost same time. In intermediate nodes in the pathway the performance will be better than these extreme points due to less extreme condition.

5.2.2 Packet Drop

The second metric which influences the performance is packet drop. More will be the packet drops more will be the retransmissions leading to greater transmission time and generation of greater network traffic. Again packet drop is considered at two extreme ends of the routes as all the intermediate nodes will lie in between source and destination path. If any node involved in the pathway goes beyond two extreme points e.g. intermediate vehicle overtakes end destination node this means it has already transmitted the packet since data transfer rate is always greater than physical speed of the vehicle and similarly if at source if intermediate vehicles leaves intermediate path then it is not the fastest node in direction of destination so the transmitting node according to the algorithm will choose other node as its next hop.

5.2.3 Channel Consumption

In metropolitan cities where traffic is large, scalability of VANETs becomes an important issue. For heavy bandwidth infotainment application, safety applications and other emergency services its necessary that load generated by beaconing or normal routing process consume minimal bandwidth so that congestion can be avoided and large number of nodes can successfully communicate with each other. Therefore lesser the channel consumption due to routing overheads more scalable will be the network where number of nodes involved are large.

5.2.4 Packet Delivery Ratio

Packet Delivery Ratio (PDR) is the ratio of the packets that successfully reach destination.

PDR = [(Total no. of packets delivered) / (Total no. of packets transferred)] x 100

The simulation is performed using two different Car agents that are:

a) Car Agent running proposed Efficient and Reliable Multi-hop Routing (ERMR) protocol for VANETS.
b) Car Agent running Fastest Vehicle Multi-hop Routing protocol.
c) Car Agent running AODV routing protocol.

In given simulation scenario number of vehicles, speed of vehicle, vehicle density in a road and packet generation rate cannot be taken as one of the perimeter to compare above mentioned metrics since in the given simulation scenario to make it realistic it is designed in a way in which cars take random speed according to the profile assigned to them and traffic condition on road. Due to the same reason vehicle density is not constant during simulation and hence can't be used as a parameter for analysis with the other performance metrics. Packet generation rate as stated earlier is varying randomly between 1 -10 packets per second so this parameter can also not good to evaluate performance metric.

5.3 Performance Evaluation

The results show that the transmission by proposed Efficient and Reliable Multi-hop Routing (ERMR) protocol as compared to base Fastest Vehicle Multi-hop Routing protocol and AODV [1] protocol which is popular standard routing protocol especially for MANETS, performs more efficient routing with lesser packet loss, packet drop rate, channel consumption and with higher packet delivery as visible from graphs generated after simulation as shown in Figure 5-1 to Figure 5-7. The reason behind this is because the base FMR protocol selects shortest distance mechanism to route packets through junction without taking real time traffic scenario into consideration which results into network discontinuity if nodes to transfer message are not present on that road segment. Thus dynamic junction strategy elevates us from this problem and increases efficiency by selecting junction dynamically taking real time traffic information into account. Along with this enhanced version of the protocol also take care of sparse road traffic condition which further enhances the performance.

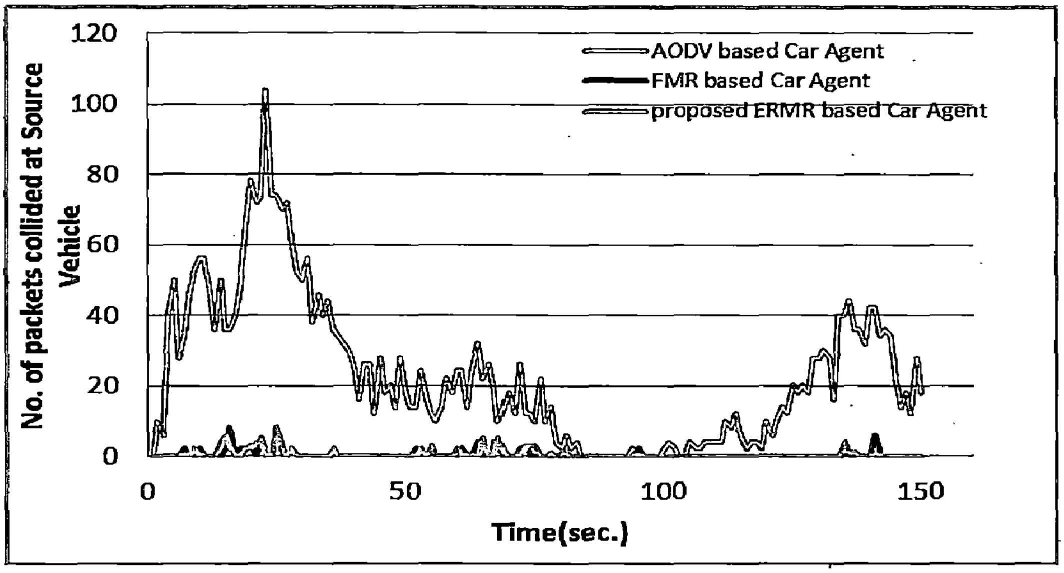

Figure 5-1: Number of packets collided at Source Vehicle

Table 5-3
Average number and standard deviation of packets collided at Source Vehicle

	AODV	FMR	proposed ERMR
Average	13.802	0.287	0.356
Standard Deviation	12.216	0.963	1.016

The traffic load increases very fast in case of congestion and traffic lights. Because of the red light period, traffic congestion increases very quickly which causes the packet collision rate, drop rate and other parameters to detoriate . In graphs shown the time from 60s to 80s was tracked as the red light time, which causes the high increase in packet collision and packet drop rate where AODV performs better than the protocol implemented because as all nodes have come to stand still due to red light or traffic jam all nodes have same speed and none of the node is able to reach destination which causes transmission of packets from one node to other but without any effective transmission towards packet delivery to the destination.

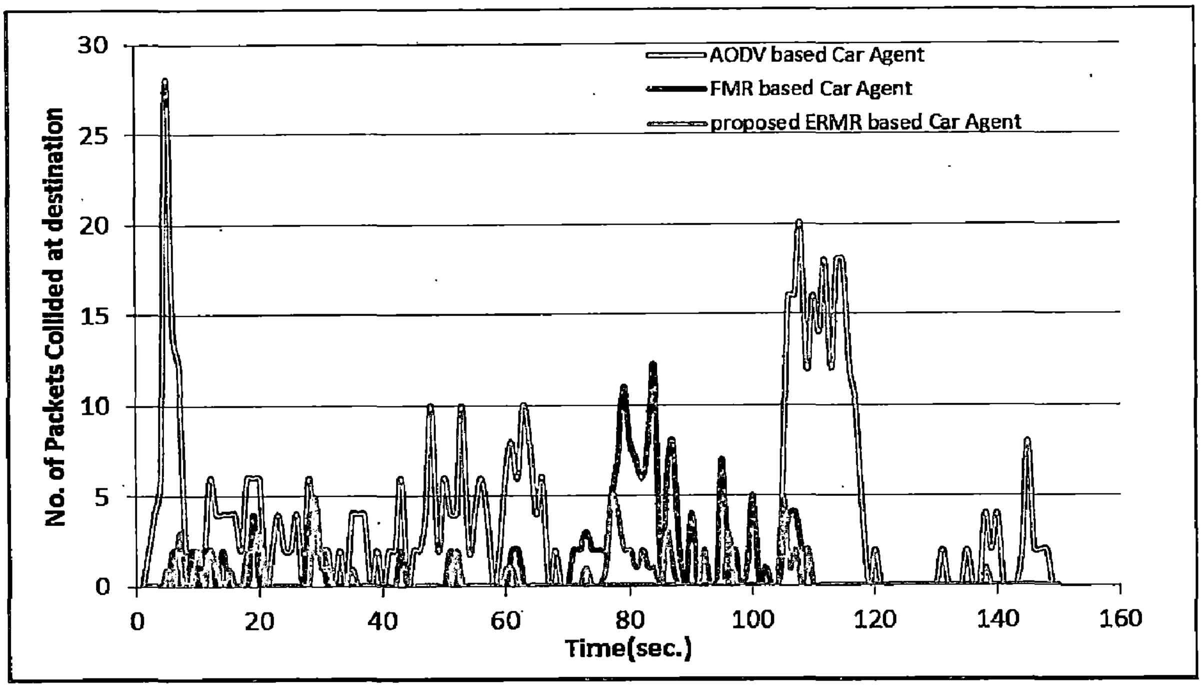

Figure 5-2: Number of packets collided at Destination Vehicle

Table 5-4

Average number and standard deviation of packets collided at Destination Vehicle

	AODV	FMR	proposed ERMR
Average	3.129	1.317	0.436
Standard Deviation	5.157	2.573	1.014

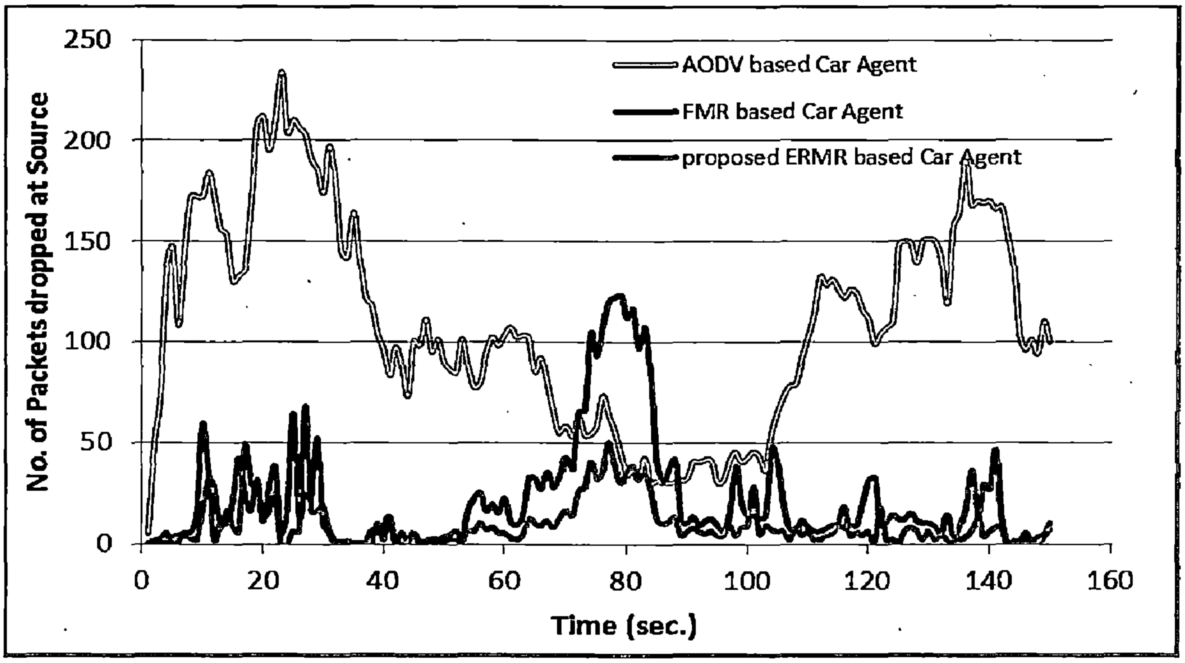

Figure 5-3: Number of packets dropped at Source Vehicle

Table 5-5
Average number and standard deviation of packets dropped at Source Vehicle

	AODV	FMR	proposed ERMR
Average	90.584	26.713	10.277
Standard Deviation	43.610	31.574	11.021

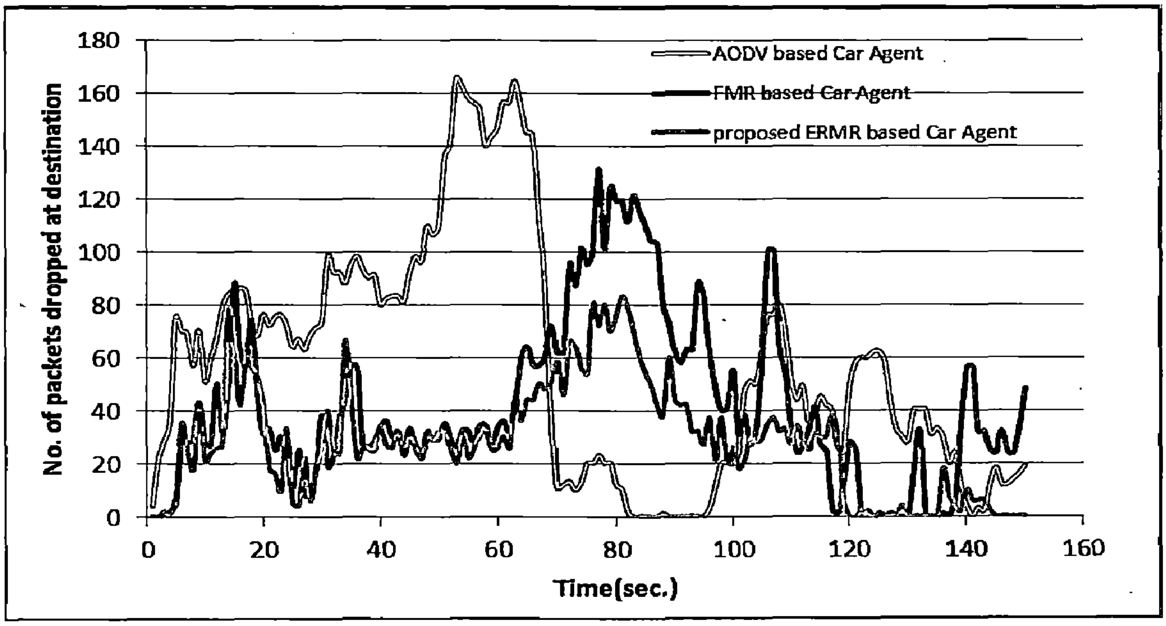

Figure 5-4: Number of packets dropped at Destination Vehicle

Table 5-6

Average number and standard deviation of packets dropped at Destination Vehicle

	AODV	FMR	proposed ERMR
Average	48.465	47.149	28.713
Standard Deviation	50.965	35.469	23.043

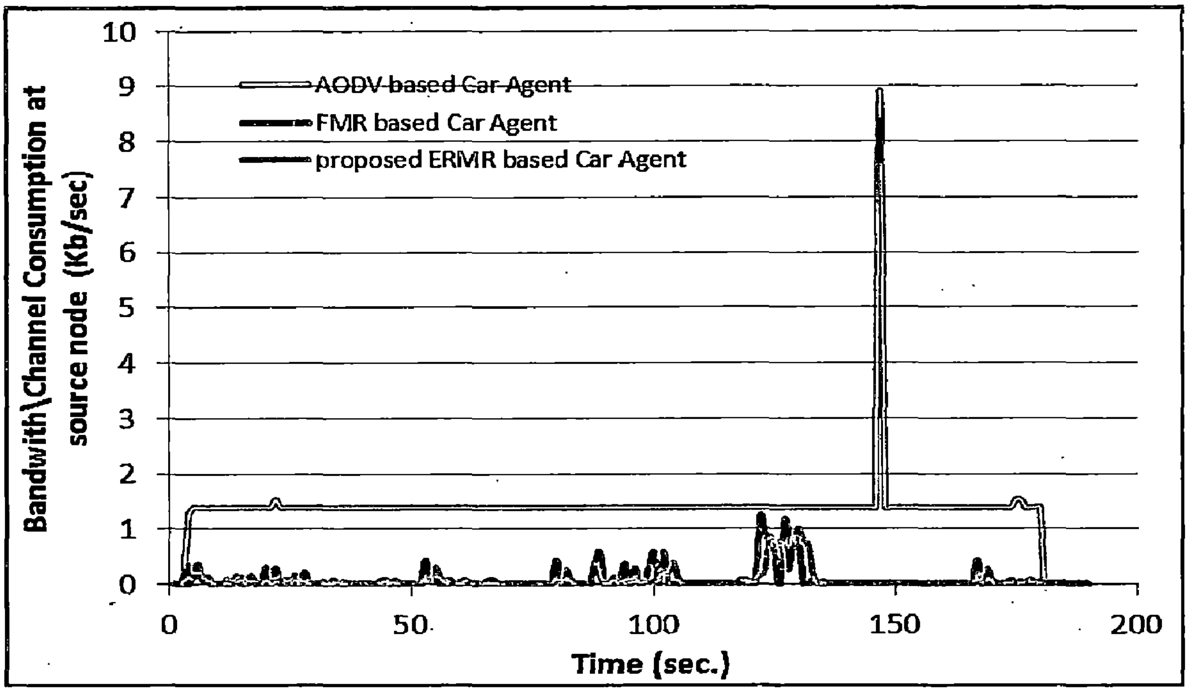

Figure 5-5: Bandwidth consumption at Source Vehicle

Table 5-7

Average bandwidth consumption and standard deviation at Source Vehicle

	AODV	FMR	proposed ERMR
Average	1.455	0.114	0.106
Standard Deviation	0.749	0.264	0.222

Table 5-8

Average bandwidth consumption and standard deviation at Destination Vehicle

	AODV	FMR	proposed ERMR
Average	2.398	4.142	2.305
Standard Deviation	2.551	1.541	1.030

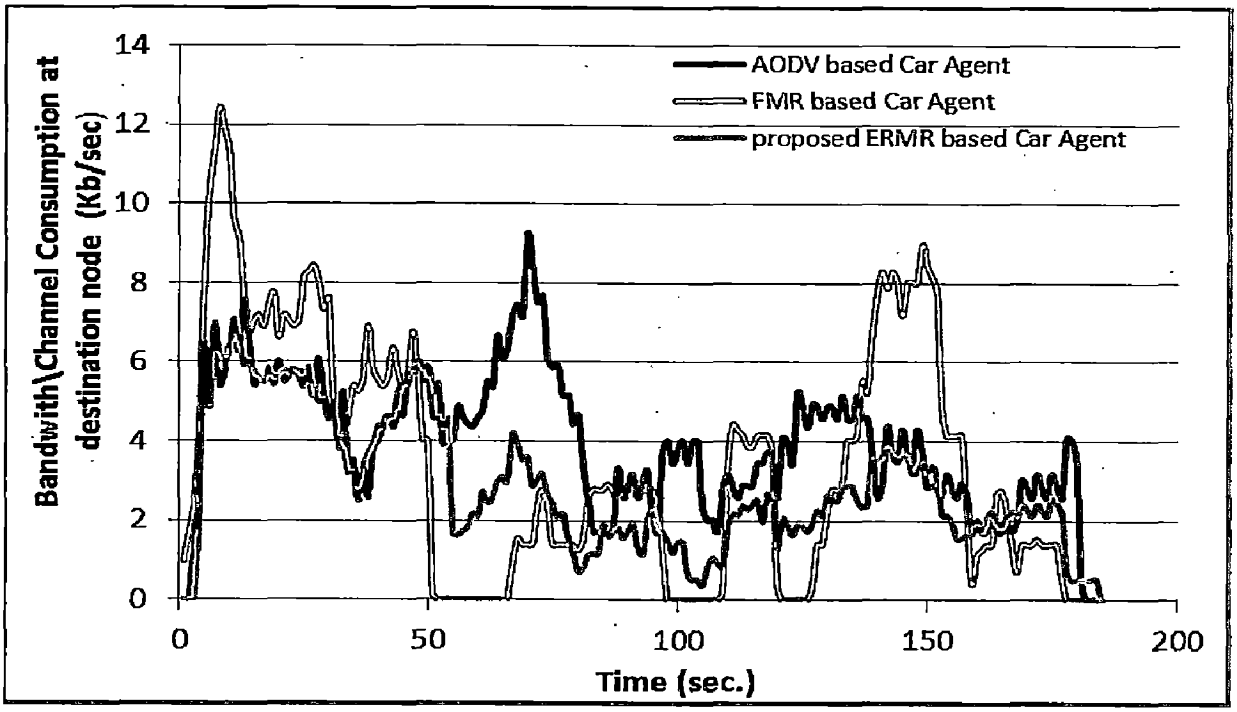

Figure 5-6: Bandwidth consumption at Destination Vehicle

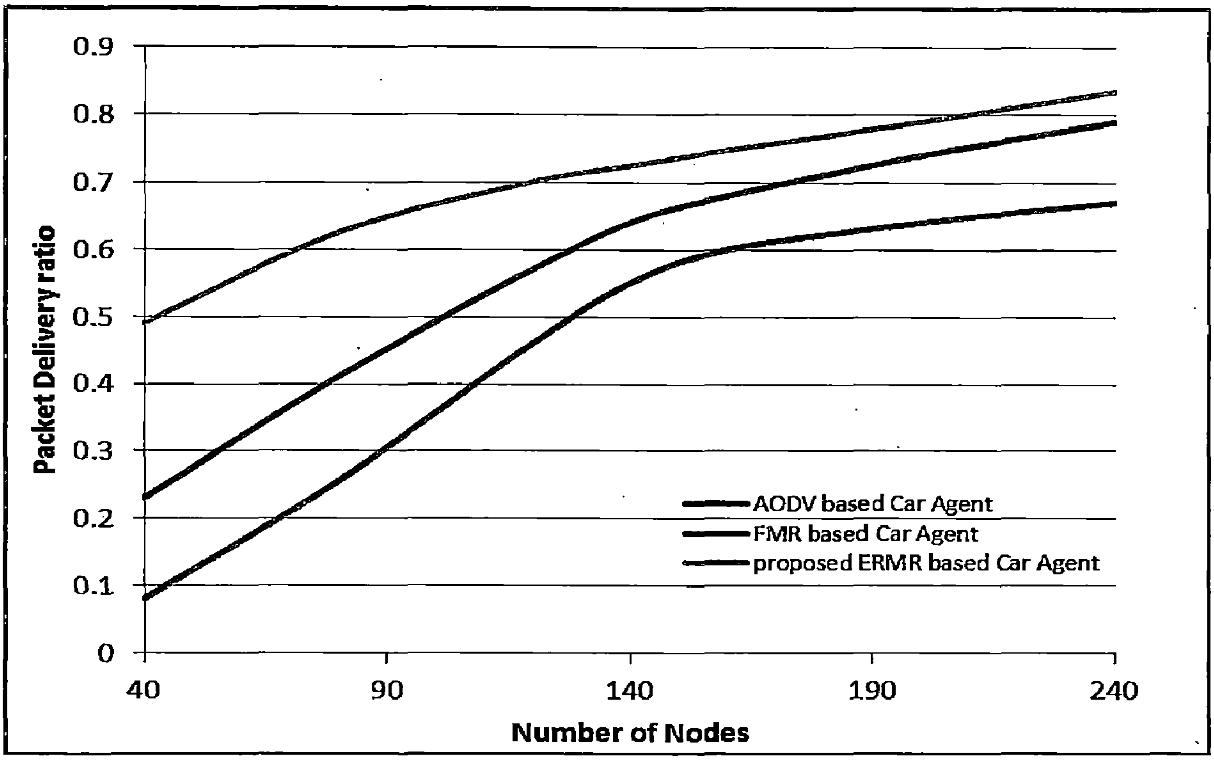

Figure 5-7: Packet Delivery Ratio vs Number of Nodes

However the proposed Efficient and Reliable Multi-hop Routing protocol gives best result this is because till 50-60 seconds both the base protocol and enhanced version are just using their forwarding module which is same in both which causes almost

Table 5-9
Average packet delivery ratio and standard deviation of the protocols

	AODV	FMR	proposed ERMR
Average	0.465	0.580	0.702
Standard Deviation	0.220	0.198	0.115

same performance, but after 60 seconds node packet reaches junction where there may be congestion or network partitioning due to red light causing traffic congestion and effective increase in the distance between source and destination. Here our dynamic junction selection module and recovery module comes into play and enhances the performance of the protocol which is quite evident from the simulation results as shown in the graph. This performance increase which also visible from comparison shown in Table 5-3 to Table 5-9 was derived due to the fact that due to junction selection always updated and most appropriate route sequence is being followed and in case of network partitioning which earlier resulted into fail transmission in this approach of store-carry-forward for sparse traffic leads to successful delivery of message.

CHAPTER 6
CONCLUSION AND FUTURE WORK

Vehicular Ad hoc Networks (VANETs) are one of the most promising applications of Ad-hoc networking technology. VANETs are not only suitable for commercial and entertainment applications but also for safety and traffic management. However, yet no standards has been set for routing in vanets and with advancement in field of VLSI technology and increase in road traffic, VANETs has been becoming hot field for research.

In this dissertation, we have investigated various routing aspects of VANETs. We have carried down study on properties of VANETs and previous research and development on routing in VANETs. By exploiting uniqueness of VANETs we have proposed a multi-hop message routing technique with dynamic and sequential junction selection approach and along with special provision for recovery in sparse traffic scenario. Extensive simulation has been conducted to demonstrate that the message loss ratio can be kept quite low, even in the presence of a large number of vehicles in proximity which may lead to contention of the channel. Performance comparisons and analysis show that the proposed schemes used in ERMR protocol performs better in terms of packet loss, packet collision, channel consumption and packet delivery ratio and has proved to be very efficient by providing stable communication and is suitable for vehicular ad hoc networks operating in city environment.

6.1 Suggestions for future work

In this work we have only dealt with network layer issues, no security issues are being handled. Security is also an important parameter and to ensure privacy in VANETs still represents a challenging issue.

Each driver has its own unique driving behavior. Thus Drivers driving pattern profile should be created and taken into account especially for quick response for emergency and security applications.

Though we have used realistic scenario but our approach still requires modifications by taking into account different mobility models with obstacles.

This work is purely dealing with issues at Network Layer, still many issues at MAC Layer has been left untouched, which can drastically increase performance.

Geographical Location Service is crucial for running this protocol, but still no highly scalable low cost service exists. Thus there is need to develop a highly scalable less expensive, and easy to deploy service to be established for using position based protocols like one proposed here to its full efficiency.

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