A Dissertation

On

TRAFFIC AWARE ROUTING PROTOCOL FOR VEHICULAR AD-HOC NETWORKS

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CERTIFICATE

This is to certify that the dissertation entitled **“Traffic aware routing protocol for Vehicular Ad-hoc Networks”** has been submitted by **Sachin Thakur** (Roll Number: **2K15/ISY/16**), in partial fulfillment of the requirements for the award of Master of Technology degree in Information System at **DELHI TECHNOLOGICAL UNIVERSITY**. This work is carried out by him under my supervision and has not been submitted earlier for the award of any degree or diploma in any university to the best of my knowledge.

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ABSTRACT

Information Technology, in the past few years has progressed to a level where it is impossible for an aspect of life to not be touched by it. It is being used to the advantage of humanity in solving difficult engineering problems and improving the quality of life. Vehicular traffic is one such area where modern technology has advanced to a phase where the ideas of interconnecting the vehicles on the road are being experimented with in different countries. These networks of interconnected vehicles are commonly known as Vehicular Ad-hoc Networks or VANETs for short. VANETs provide a platform for the implementation of road safety procedures and access to various features of internet like multimedia, emails, etc. VANETs make use of the on board communication abilities of a vehicle and pre-installed roadside Units to achieve this goal.

For efficient implementation of a VANET it is very important for its design to be based on communication protocols which uses very less resources and is also easy to incorporate. Various routing protocols have been developed for this purpose by numerous researchers all over the world. In this thesis, a new approach to vehicular networking is discussed, which hopes to provide an alternative way of communication between the nodes in a VANET.

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Chapter 1

INTRODUCTION

1.1 Vehicular Ad-hoc networks (VANETs)

With the ever escalating amount of vehicular traffic activity on the roads, the safety and security of the drivers and passengers is of paramount gravity. To alleviate these, Vehicular Ad-hoc networks (VANETs) are being presented as the systems where vehicles would be perceptive of the locality and supply the driver with required inputs to take precautionary actions to ensure safety. The system is designed to detect and identify important traffic events like overtaking, sudden braking and informing all neighbouring vehicles about the vehicle's state. Some of the other applications of VANETs include providing aid to the drivers via maps and directions and striving for passenger comfort by providing infotainment through streaming of audio-video content [1].

Today, vehicular networking has grown into a necessary technology that can assist the authorities in the implementation and improvement of many applications pertaining to vehicular traffic and the users dependent on it. These applications are not lab experiments anymore because the vehicular networking enables the development of Intelligent Transport Systems (ITS) which can be utilized for smooth operation and management of the traffic flow. They can further help the drivers in maintaining the road safety and prevention of highway collisions, and also support the implementation of infotainment applications for the passengers of the vehicles [2].

Some of the most common examples of such systems are automated toll collection system, emergency warning system, etc. The government authorities all over the world are trying to coordinate efforts to standardize the guiding principles, communication protocols and requirements in such systems so that they can be easily implemented [3].

Vehicular Ad-Hoc Network (VANET) in this regard is a fairly new technology concept that is trying to integrate wireless Local Area Networks (WLAN), ad hoc networks and cellular networks to achieve intelligent vehicle to vehicle communications and also enhance highway traffic efficiency and safety. VANETs are differentiated from the other types of ad hoc networks based on their node movement attributes, compound network architectures, and various implementation scenarios [2]. Therefore, VANETs present many uncommon networking research problems, and the development of an efficient routing protocol for a VANETs is of utmost importance.

By using the assistance of VANETs, vehicles can very easily and efficiently communicate with each other and with the roadside units. IEEE 1609.1 to 4 and IEEE 802.11 defines Dedicated Short Range Communication (DSRC) and Wireless Access in Vehicular Environment (WAVE) standards for vehicular communication [3]. Using DSRC and WAVE, the process of communication among the vehicles become very easy and efficient. VANETs, in which the vehicles can move at high speeds employ an on-demand network that is highly dynamic and infrastructure-less. The most important function of VANETs is the transmission of datagrams from a location to another location, securely and efficiently.

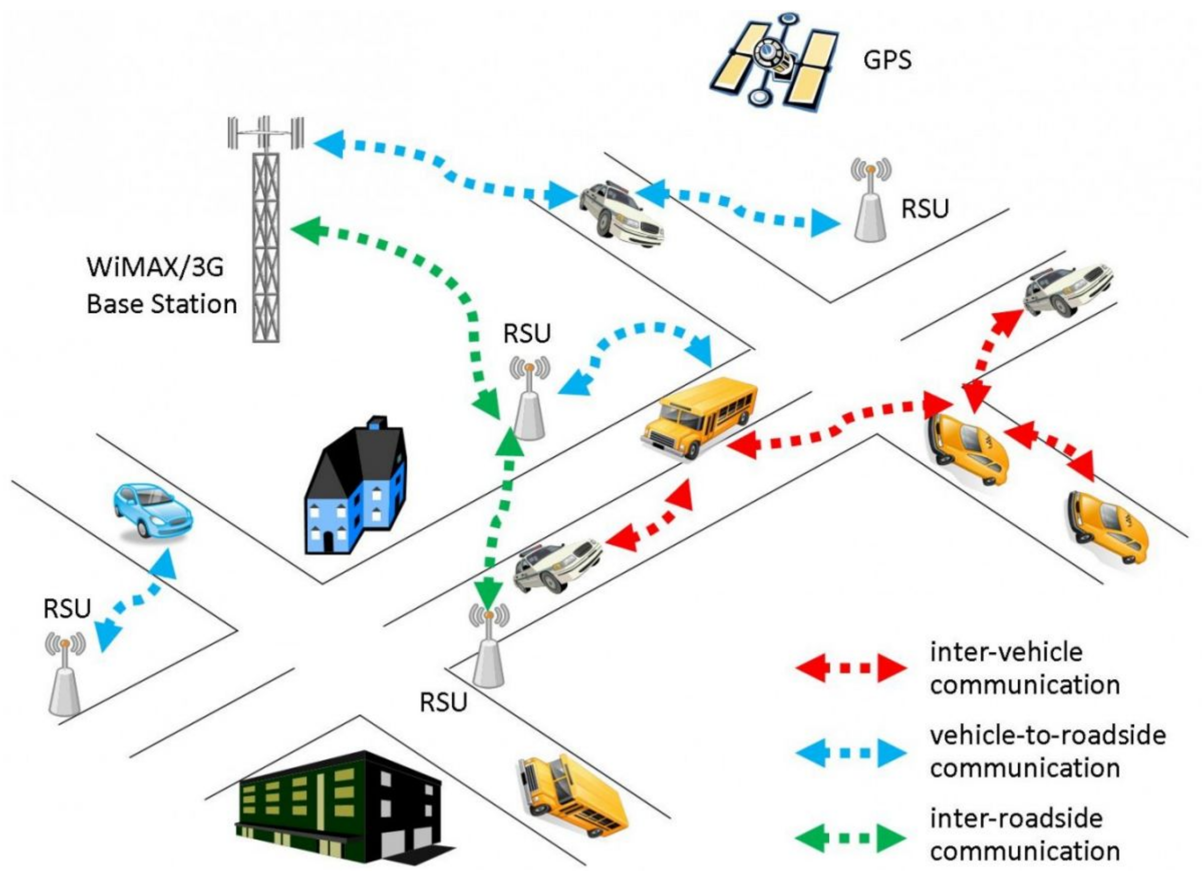

Figure 1.1 - A sample VANET scenario

Vehicular Ad-Hoc Networks are designed and implemented while keeping in mind the integration of the capacities of new technologies in wireless networking. This is done to supply omnipresent connectivity when the users are at motion on the road, who would in other cases be connected to the rest of the world using some other networks at their own homes or at their workplaces, and streamlined inter-vehicle communications that ITS. Due to this, the VANETs are also known as Vehicle-to-Vehicle (V2V) communications or Inter-vehicle Communications (IVC). ITS encompasses a myriad of applications, for example, traffic flow control, collision prevention, cooperative monitoring of traffic, neighbouring information services, blind crossing, and alternative route suggestion in real time. Providing ubiquitous connectivity to Internet to the mobile vehicle nodes, thus enabling users to download files such as music, etc., play movies, send emails, or play online video games, is another major application for VANETs [4].

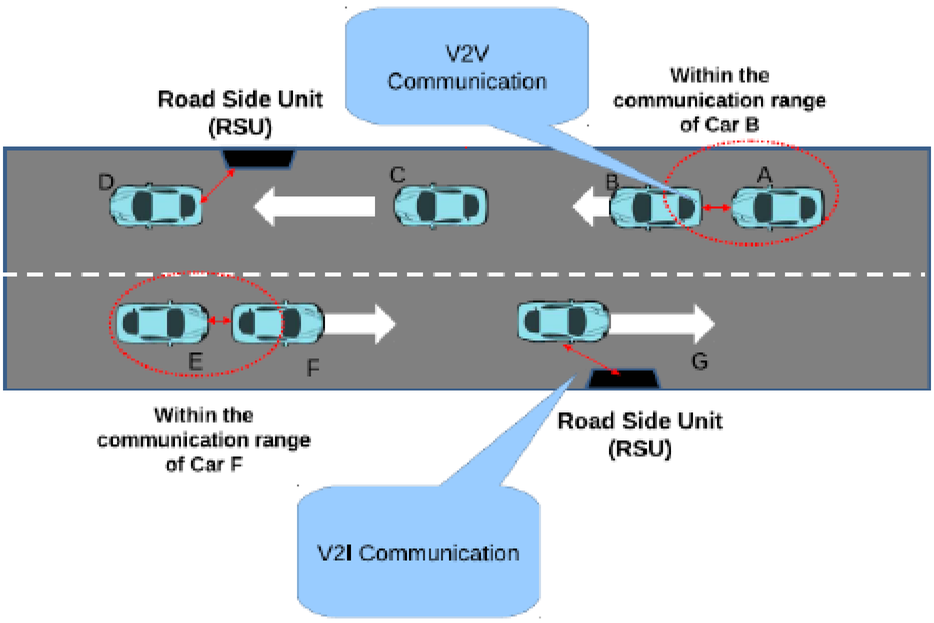

Figure 1.2 - Creating an Ad-hoc Network using Vehicles

Because the geographical road topology and traffic conditions constrain the distribution and mobility pattern of vehicles, therefore, digital maps and geographical locations of vehicles can be useful for making routing decisions. But there can be certain problems, for example the fluctuating vehicular mobility often can lead to unreliable connectivity and in this way result in unstable service quality. Therefore, routing protocols for VANET should be competent enough to deal with such problems and hindrances [3].

In most of the scenarios, the position-based routing protocols are generally the most suitable for VANET. In such protocols, precise information regarding the network and traffic conditions are of utmost necessity to circumvent the selection of disadvantageous routes. Few of the studies have accepted the notion of dissecting a segment of the road into cells of fixed-size and after that selecting a vehicle closest to the centre of the cell as the traffic information aggregator in the respective cell [5]. Nevertheless, the distribution of vehicles is generally random, and therefore, not all of the appointed information aggregators may always be positioned near to the corresponding cell centres. As a consequence, some of the vehicles can not be involved in the process of collecting the traffic information owing to the inadequate transmission coverage of the appointed information aggregators. Therefore, the accumulated information may not always characterize the actual conditions of the activity on the road.

1.2 Applications of VANETs

VANETs facilitate a very large domain of utilities – from a simple single hop information distribution of, for example, cooperative awareness messages to the very complex multihop distribution of packets spanning over very large distances. Many applications pertaining to the MANETs (i.e., Mobile Ad-hoc Networks) can also be extended to VANETs, but the actual details are often varying. Instead of random movements, the mobility patterns of vehicles generally tend to be of an ordered manner. And also, majority of the vehicles can be limited in their respective range of motion, e.g., by being compelled to move on a particular road. Therefore the communication interchanges with the roadside units are characterized as reasonably accurate [6].

Most of the vehicular networking applications can be broadly classified into the following three major categories:

1. Active road safety
2. Traffic management
3. Infotainment

1.2.1 Active Road Safety

The primary motive for the deploying the active road safety applications is to lower the risk of traffic mishaps and consequently the deaths and/or injuries of the driver and the passengers in the vehicles [7]. A considerable percentage of roadside mishaps that take place every year all over the world are related to the intersection, or the head, rear-end and lateral vehicle collisions. Such collisions with other vehicles can be avoided if the drivers are provided assistance and information on time before the accident. This can be achieved through the active road safety applications. Sharing of information between roadside units and vehicles is necessary in such applications which can then be used to predict collisions, and therefore avoid the tragedy on time [3]. Such information generally represents vehicle location, intersection location, velocity and distance heading. As a further matter, the information interchange between the roadside units and the vehicles can be used to pinpoint the hazardous locations and accident-prone areas on the roads, for example, potholes or slippery segments [8]. Following are some of the uses of such applications:

1. **Lane change assistance:** The probability of lateral collisions involving the lane changing vehicles with may have a blind spot for larger vehicles, for example, a truck, is decreased, thereby reducing the risk of collision.

2. **Intersection collision warning:** The roadside units or the neighbourhood vehicles collect the information regarding the risk pertaining to the lateral collisions for those vehicles that are approaching the junction on the road, and then the information is transmitted to the approaching vehicles thereby decreasing the probability of lateral collision.

3. **Overtaking vehicle warning:** There is also a risk of vehicle collision when a vehicle is trying to overtake another vehicle on the highway. For example, Vehicle A is trying to overtake Vehicle B, and meanwhile another vehicle, let’s say Vehicle C is already trying to overtake Vehicle B. This can lead to a collision between Vehicle A and Vehicle C. To prevent such an outcome, Vehicle C can inform Vehicle A to stop the overtaking process.

4. **Head on collision warning:** When two vehicles are travelling in the opposite directions, then there is a risk of a head-on collision between the two vehicles, especially on narrower roads. This situation can be prevented by sending an early warning message to the involved vehicles on time so that the drivers know about the approaching vehicle from the opposite direction.

5. **Rear-end collision warning:** The maximum risk of occurrence of a rear-end collisions is in situations such as a road curvature or a slowdown (for example, hilly areas or sharp curves). In such situations, a vehicle's driver can be informed about the probable danger of a rear-end collision.

6. **Cooperative forward collision warning:** The vehicles can cooperate among themselves to detect the risk of a forward collision incident on time. Therefore, such an accident can then be prevented by assisting the driver.

7. **Emergency vehicle warning:** There can be situations of emergency which require the vehicles on the road to free up an emergency lane for vehicles such as police cars, fire brigades, or ambulances. This can be achieved by using the vehicular networks to inform the vehicles on the road to free up the emergency lane. Such an information can be broadcasted in the entire region by the roadside units and the vehicles.

8. **Pre-crash Sensing/Warning:** There can be some cases where the accident is unavoidable and is certain to happen. To limit the damage from the accident, equipment such as airbags, bumpers, actuators, etc. can be used in an optimum manner. To facilitate their proper use, the information about the predicted crash, the position and the movement of the vehicle needs to be actively exchanges between the vehicles and the roadside units.

9. **Cooperative merging assistance:** At the junctions, the vehicles can use the roadside units and cooperate with each other to avoid collisions while involving in a junction merging maneuver.

10. **Emergency electronic brake lights:** There can be situations when a vehicle on the highway has to hard brake. This may lead to a collision with a vehicle coming from behind. To prevent such an accident, the hard braking vehicle can inform the other vehicles and roadside units.

11. **Wrong way driving warning:** There is a risk of collision in a situation when a vehicle has detected that it is moving in the wrong way. In such a situation the concerned vehicle can inform its circumstances to the roadside units and other vehicles on the road segment.

12. **Stationary vehicle warning:** There can be situations in which a vehicle may become stationary in the middle of the road owing to a breakdown, or an accident. To prevent causing an accident with the other vehicles, the stationary vehicle can inform the nearby roadside units and vehicles of its situation.

13. **Traffic condition warning:** While moving on the highway if a vehicle comes across some rapid traffic situation which may be of concern, then it can transmit such information to the neighbouring vehicles and the roadside units, so as to prevent any mishaps on the road.

14. **Signal violation warning:** There may be a situation in which a roadside unit detects a violation of the traffic light signal. Information regarding such a violation can be then broadcasted by that roadside unit to the neighbouring units and vehicles to implement the traffic safety rules.

15. **Collision risk warning:** In a situation where a roadside unit comes to know of a probable collision between vehicles that are without the ability to communicate with each other, the roadside unit can transmit the information to all its neighbouring vehicles to warn them of the danger.

16. **Hazardous location notification:** If a roadside unit or a vehicle happens to come across a hazardous location on the highway, for example, an ongoing construction work, or an obstacle on the highway, or a slippery segment of the road, then it can

warn the neighbourhood vehicles and roadside units about such conditions, and thus prevent a possible accident.

17. **Control Loss Warning:** There can be a particular situation in which it is required to enable the vehicle's driver to compose a control-loss message and broadcast it to the neighbourhood vehicles and roadside units. Such a message can inform the nearby vehicles of the event and they can then ascertain the importance of the event and warn the drivers, if required.

1.2.2 Traffic Management

The main focus of the application concerned with traffic management and efficient traffic flow is on enhancement of the vehicular traffic movements, traffic assistance and traffic coordination and also supply the updated neighbourhood environment data, local maps and most importantly, vital data packets that are time bound and/or geographic region bound. The 2 standard categories of this type of utilities are Cooperative navigation and Speed management [8].

1. **Cooperative navigation:** Such applications aim at the improvement of the traffic efficiency through management of the vehicular navigation on the highway through cooperation between vehicles and roadside units (i.e., V2I) and through cooperation among vehicles (i.e., V2V). Common examples of such applications are platooning (which allows vehicles to form an electronically coupled "road trains" by closely follow a leading vehicle which provides acceleration and steering information), cooperative adaptive cruise control, and traffic information and recommended itinerary provisioning.

2. **Speed management:** The main purpose of the applications concerned with speed management is to help the driver of the vehicle in regulation of the speed of the vehicle for uneventful driving and also prevent any unnecessary stoppages on the highway. Most common example of such applications are, regulatory speed limit notifications, etc.

1.2.3 Infotainment

Infotainment applications refer to a type of applications which are focused on delivering media which provides a combination of information and entertainment.

1. **Cooperative local services:** The main focus of such application is obtaining infotainment from locally based services, for example notifications about the points of interest in the neighbourhood [8].

2. **Global Internet services:** Such applications are mainly focused on the data that can be acquired from the Internet providers. Some of the most common examples are, music streaming, backseat video game playing, movie streaming, etc [8].

1.3 VANET Requirements

VANETs need some basic networking technologies for smooth operation of the applications. There are some most common vehicular networking applications requirements which are necessary for implementing a vehicular networks [9]:

1. **Radio communication capabilities:** Vehicular networking requires capabilities such as radio frequency channels, single hop radio communication range, radio communication channel robustness, available bit rate and bandwidth.

2. **Network communication capabilities:** A vehicular network should be capable of different modes of dissemination such as: unicasting, broadcasting, multicasting, geocasting (broadcasting only within a specified geographic region). Furthermore, the network should have provisions for congestion control, data buffering, message priority, IPv4 and IPv6 addressing support, channel and connectivity management, management of mobility related to the changes in the point of attachment to the Internet.

3. **Vehicle absolute positioning capabilities:** A vehicular network can use facilities such as Global Positioning System (GPS), Global Navigation Satellite System (GNSS), etc. to boost its operation capabilities.

4. **Vehicle communication security capabilities:** There should be provisions in a vehicular network for respecting anonymity and privacy of the users, confidentiality and integrity of data, authenticity of received data, and protection from the external security threats.

Chapter 2

LITERATURE SURVEY

2.1 Network Architectures

MANETs (i.e., Mobile Ad-hoc Networks) usually are not dependent on any fixed infrastructure for communicating with nodes and transmitting the data packets. VANETs (Vehicular Ad-hoc Networks) extend the same fundamental concept by basically applying it to the very dynamic domain of vehicular transportation [2].

VANET architecture can be classified into three broad categories:

1. Pure Cellular or WLAN architecture
2. Pure Ad-hoc architecture
3. Hybrid architecture

2.1.1 Pure Cellular or WLAN Architecture

VANETs may utilize WLAN access points and fixed cellular gateways at traffic junctions to connect to Internet, collect information about traffic or for routing requirements. This scenario depicts a pure cellular or WLAN vehicular network architecture. VANETs can merge both WLAN as well as cellular networks to form the architecture so that a 3G connection is used where a WLAN access point is not available.

Although, a pure cellular-based vehicular network is not practical due to the very high cost of communication between the base stations and the vehicles and the high number of handoff incidents occurring at the base station, taking into consideration the high mobility of the vehicles [4].

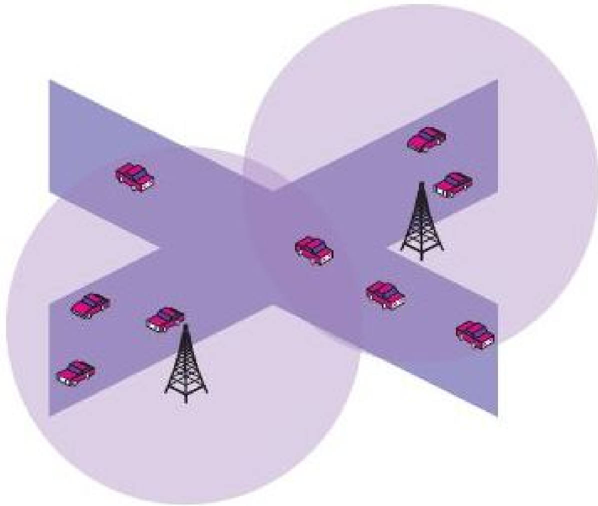

Figure 2.1 - Pure WLAN or Cellular architecture

2.1.2 Pure Ad-hoc Architecture

In such scenarios, all the roadside wireless devices and the neighbourhood vehicles can establish a mobile ad hoc network to facilitate inter-vehicle communications and thus implement certain applications, for example, a crossing without any light control (i.e., a blind crossing). Stationary gateways around the roadsides can extend connectivity to the mobile vehicles but will in the end be impractical when taking into consideration the costs costs involved for the entire infrastructure [4].

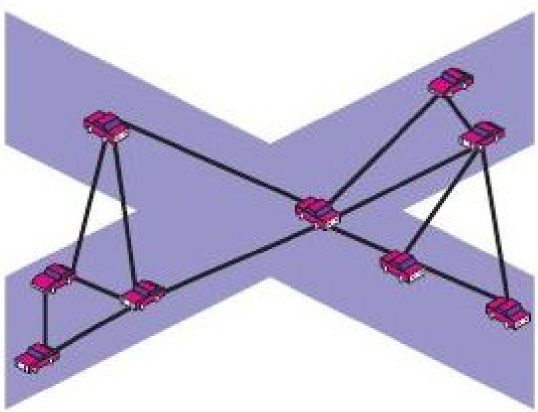

Figure 2.2 - Pure Ad-hoc architecture

2.1.3 Hybrid Architecture

The above two architecture can be amalgamated together to form another architecture known as the hybrid architecture. Such a hybrid architecture make use of nodes that have both cellular as well as WLAN capabilities. These nodes (i.e., vehicles) are tasked with the job of acting as the gateways and routers so that they can be communicated with using multi-hop links by only those vehicles that have WLAN capability [10].

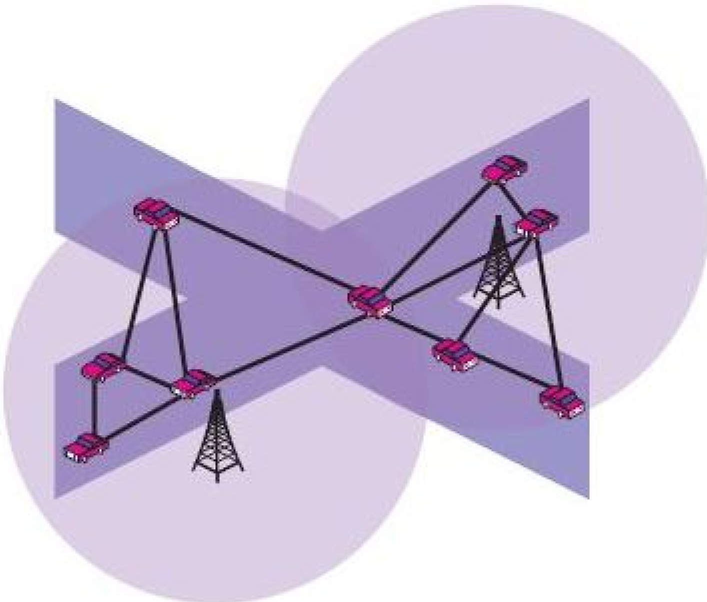

Figure 2.3 - Hybrid architecture

2.2 Network Characteristics

Vehicular Ad-hoc Networks are composed of vehicles containing radio communication capability which can serve as mobile nodes and also as routers for the other nodes in the network segment neighbourhood. Despite the resemblances to other ad hoc networks, such as low bandwidth, short range of radio transmission, self-management, and self-organization, Vehicular Ad-hoc Networks can be differentiated from most of the other ad hoc networks based on following characteristics [2]:

2.2.1 Highly dynamic topology

Because of the high mobility of the nodes (i.e., vehicles), the topology of vehicular networks changes constantly. For example, Assuming that each vehicle has a transmission range of 250 metres for wireless communications, therefore there is a communication link between two vehicles if they are less than 250 metres apart from each other. But, considering the case in which the two vehicles with the speed of 25 metres per second start to move in opposite directions from each other. In such a case the communication link will only last for a mere 10 seconds in the best case.

2.2.2 Frequently disconnected network

Now, consider the case where the vehicle density happens to be very low in a segment of the highway. In such a case there is a high probability that the network is going to be disconnected in that segment of the highway. Because of this very reason, the connectivity of the vehicular networks can be highly infrequent. Some applications require constant access to the Internet. They cannot operate if the network connectivity is bad. One possible solution to this problem is the pre-deployment of numerous access points or relay nodes along the highway to maintain the connectivity, but this could increase the cost of vehicular networking significantly.

2.2.3 Sufficient energy and storage

Since the nodes in the vehicular networks are vehicles, therefore, they have enough battery power, processing capabilities, and storage capabilities as compared to most other mobile ad-hoc network implementations which may use handheld devices or small sensors with very limited resources, for example Wireless Sensor Networks (WSNs) have very limited processing capabilities and limited battery power. But there is no such issue in Vehicular Ad-hoc Networks.

2.2.4 Geographical type of communication

Most of the other networking applications utilize the standard concepts of networking such as, unicasting, broadcasting, and multicasting. The end points, in such communication scenarios, are defined in terms of the ID of the node or the ID of the group. But in vehicular networking, there is a different type of communication which is used to address the geographical regions. The messages to be forwarded can be time bound and/or geographical region bound.

2.2.5 Mobility modelling and prediction

Nodes in the vehicular networks are generally restricted in mobility patterns by the predefined streets, roads, or highways, therefore, provided the velocity of the vehicle and the geographical map, the future location of the vehicle can be approximated to a certain degree depending upon the traffic conditions. And because of the highly dynamic topology and highly mobile node (vehicle) movement, prediction and mobility models assert a very crucial part in design of the network protocols for vehicular networks.

2.2.6 Various communications environments

Vehicular networks are most commonly deployed in two particular communication scenarios. Firstly, in a highway traffic layout, where the neighbourhood of the node is fairly simple and uncomplicated, and most of the node movements are in single dimension only. Therefore, establishing and maintaining communication links is fairly easy in such environments. Secondly, in an urban layout, where the neighbourhood of the node can be very complex owing to the topology of the city. The roads in an urban neighbourhood can be segregated by various obstacle such as trees, flyovers, buildings, etc. This results in numerous difficulties in establishing and maintaining the communication channels between the vehicles and the roadside units, as the network may get frequently disconnected because of the obstacles if the signal is not strong.

2.2.7 Hard delay constraints

Consider a situation in an highway system, when a sudden brake event happens. In such a scenario the message about the sudden brake should be transmitted and received in a fixed time constraint to prevent an accident. In these types of applications, maximum delay is much more crucial than average delay. Therefore, depending upon the requirement of the application, some vehicular networks may not necessitate high bandwidth but instead may be time-bound, i.e., may have hard delay constraints.

2.2.8 Interaction with on-board sensors

On-Board Sensor (OBU) is a device inside the vehicle which is used to processes the data collected from various sensors inside the vehicle and is responsible for communicating with the outside network, i.e., with roadside units and other vehicles in the neighbourhood. The nodes (vehicles) in a vehicular network are assumed to be stocked with OBUs so as to facilitate communication between the nodes and the roadside units, and also help in the routing procedure.

2.3 Routing Protocols

As a consequence of the highly dynamic and constantly changing topologies in the vehicular networks, routing in Vehicular Ad-hoc Networks is different from routing in Mobile Ad-hoc Networks.

Designing a routing protocol that is dynamic and can help in transmission of the data packets from one vehicle to another is one of the biggest problems in VANETs. Finding and maintaining routes in the vehicular networks is very challenging owing to the highly dynamic nature of the vehicles (nodes) in the VANET [11].

Numerous different protocols have been suggested for routing in vehicular networks. They can be classified into 5 major categories [2]:

1. Ad-hoc based routing
2. Location based routing
3. Cluster based routing
4. Broadcast routing
5. Geocast routing

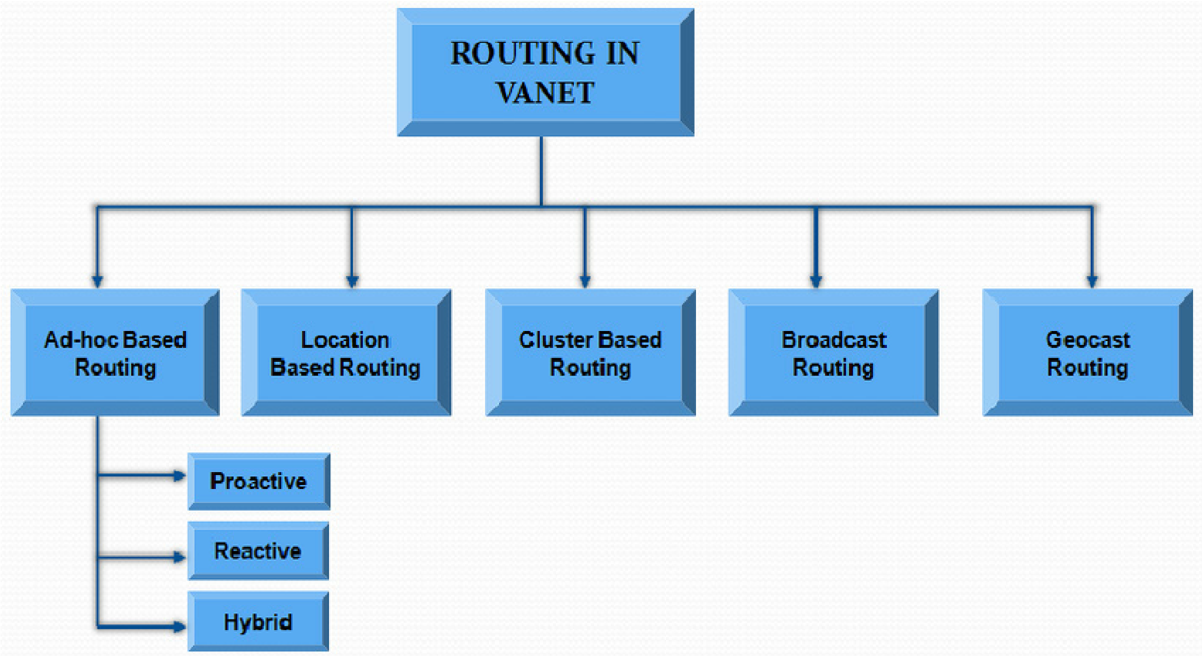

Figure 2.4 - Classification of Routing Protocols

2.3.1 Ad-Hoc Based Routing

Vehicular networks are generally infrastructure-less. Ad-hoc protocols for VANET topologies can be further classified into 3 groups [4]:

1. Proactive
2. Reactive
3. Hybrid.

In proactive protocols, the routing table of the nodes in the vehicular network is continuously updated with information concerning the new routes inside the network. After that, periodic

HELLO packets are sent to pass the new information around to all nodes. However, this process can generate considerable control overheads.

In reactive protocols, for example Dynamic Source Routing (DSR) [12], Ad-hoc On-demand Distance Vector (AODV) [13], Bordercast Resolution Protocol (BRP) [14], the nodes (vehicles) only exchange the control data whenever there is a need for it. Such an approach can diminish overheads related to the establishment of the communication link, and therefore, help in the distribution of the real information swiftly. However, this approach can still increment excessive overheads for example, maintaining of the routes, discovering the route to disseminate the messages. The process for finding the route is started by sending a RREQ (Route Request Message) packet. When the request arrives at the destination node, a RREP (Route Reply Message) packet is sent back to the node that sent the RREQ packet.

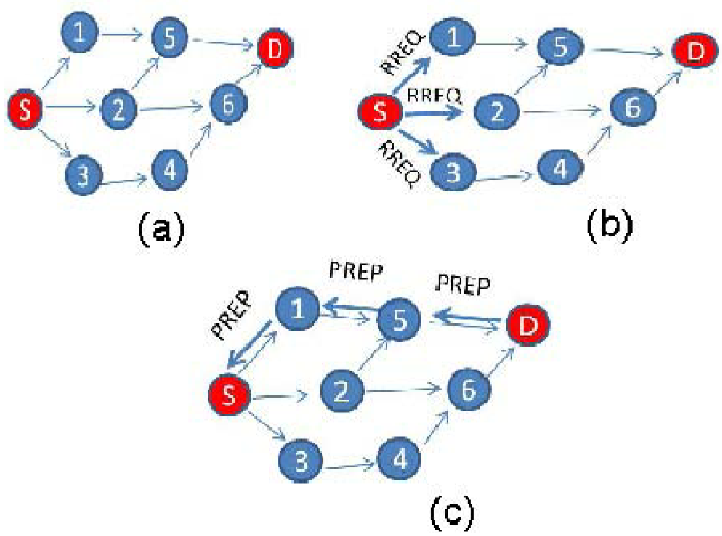

Figure 2.5 - Route discovery using Flooding

Other than the reactive and proactive protocols, there are also hybrid [15] types of protocols which use some functionalities of both, for example, TORA (Temporally Ordered Routing Algorithm) [16], in which localised routing messages are sent to a small set of nodes in the neighbourhood of the change.

In real world scenario, however, due to the highly dynamic nature of the vehicles (nodes), most of the protocols designed for Ad-hoc routing suffer from low communication throughput and poor route convergence.

2.3.2 Location Based Routing

Vehicular networks, in general, put constraint on the mobility of the of the nodes (vehicles) in bidirectional movements restricted to follow the streets and roads. Therefore, using information about the geographical location from traffic models, street maps, or the navigational systems of the cars for developing routing strategies makes much more sense. Despite the fact that the nodes (vehicles) in the network can utilize the location information for making routing decisions, there are still difficulties to be overcome in such algorithms.

Majority of the location based routing algorithms use the geographic location data to make forwarding decisions. For example, in greedy routing the packet is always forwarded to the node (vehicle) which is geographically nearest to the destination node (vehicle). One of the best known location based routing protocols is Greedy Perimeter Stateless Routing (GPSR) [17]. It uses a combination of the greedy routing with face routing. Whenever greedy routing fails and it is stuck in the local minima it uses face routing to get out.

In position based routing protocols, the route can get established whenever there is a need for it. Therefore, position based routing protocols, unlike topology based protocols, don't require any kind of route maintenance. In the vehicular networking environments, this can decrease unneeded constraint on the bandwidth that is already insufficient.

2.3.3 Cluster Based Routing

Cluster Based Routing (CBR) was mainly introduced for the purpose of reducing the network traffic and routing overheads in vehicular networking environments. The main concept behind Cluster Based Routing is to design a networking environment where small groups of nodes (vehicles) are formed into separate clusters [18]. One of the nodes in every cluster is chosen to act as the cluster-head. The cluster head is responsible for coordination among the nodes in the cluster and also with the other nearby cluster-heads. This is done to provide scalability in the network infrastructure.

Inside a cluster, the nodes can communicate with each other through direct links. To perform communication between two clusters, the cluster-heads are involved. Cluster based routing protocols, however, suffer from the highly dynamic VANET systems which causes the overhead during the formation and maintenance of the clusters [19].

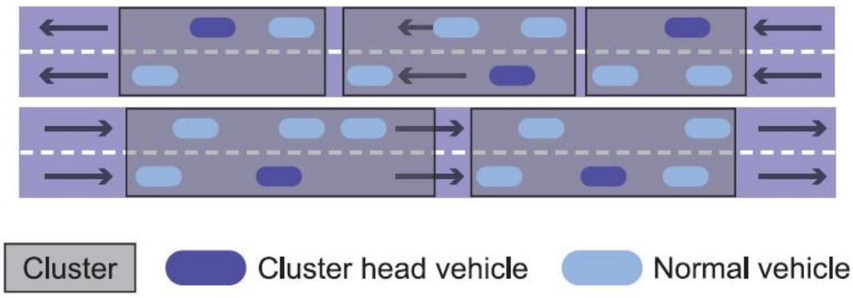

Figure 2.6 - Cluster based routing

2.3.4 Broadcast Routing

In vehicular networking environments, broadcast routing is one of the simplest routing techniques. This approach is primarily used when the packet is needed to be disseminated to the node that is beyond the transmission range. Flooding technique is used to transmit the packets over the entire network. Each node, on receiving the packet, rebroadcasts the packet on all of its open communication links except the one it came from. This ensures delivery of information, but uses extensive resources of bandwidth [20].

Flooding is very easy to implement and ensures that the packet will ultimately arrive at the destination node if the network is not disconnected. The performance of flooding is relatively well when implemented in a small group of nodes. However, as the number of nodes increases in the vehicular networking environment, the performance begins to drop very rapidly. For a single broadcast message transmission, the bandwidth required can increase exponentially with the increase in the number of nodes in the network. Bandwidth is consumed very rapidly when collisions and contentions occur as each node receives and then rebroadcasts the packet nearly at the same time.

Most common uses of the broadcast routing in vehicular networking are, sharing weather, emergency, traffic, road conditions between the vehicles, and also transmitting important announcements, warnings, and advertisements. Broadcast routing can also be used in the route discovery phase of the unicast routing protocols to discover the most cost-effective path to the destination. Selective forwarding can be utilized to prevent causing network congestion and significantly cut down the overhead caused by flooding.

2.3.5 Geocast Routing

Geocast routing in vehicular networking environments is the type of routing that is concerned with transmission of information in a particular geographic region of relevance. In geocast routing protocols the fundamental concept is to narrow down the exploration for the next hop to a particular Zone Of Relevance (ZOR). For example, in a case where a vehicle is involved in a road accident, it can identify the event by detecting events like airbag ignition on its own, and then send messages to all the nearby vehicles in that specific region about the occurrence of the accident [21]. To avoid hasty and unnecessary reactions, vehicles which are outside that particular ZOR are not notified.

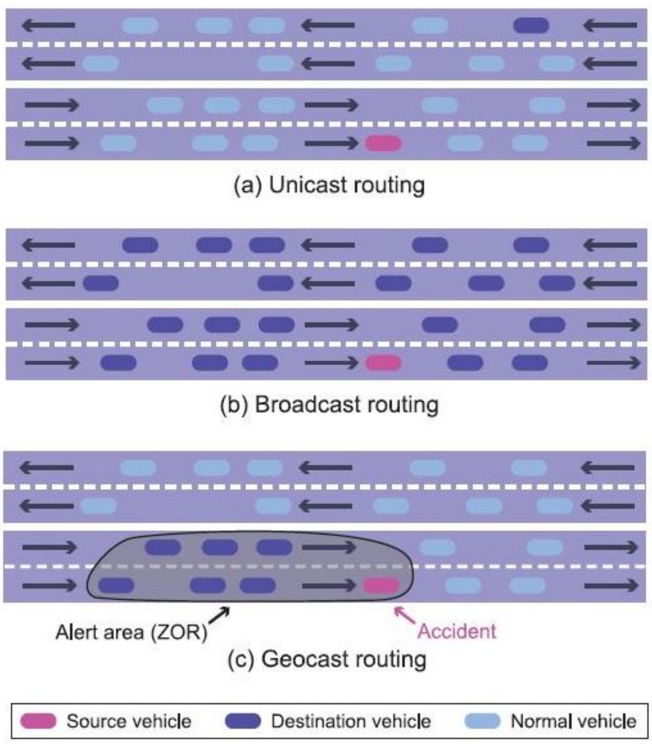

Figure 2.7 - Different communication scenarios in VANETs

Chapter 3

PROPOSED FRAMEWORK

3.1 Geocasting

Geocasting refers to the process of dissemination of data packets to a group of destinations in a vehicular network assimilated together by their geographical coordinates. In VANETs, geocasting is a very important issue. In this thesis, a different approach is proposed to address the geocasting problem in vehicular networking environments. The minimal cost must be found for a data packet to be relayed from one node to another specific node in a given geographical region [21].

To address this challenge, an Infrastructure-assisted geocasting approach [22] for vehicular networks is proposed. To represent the geographical region space recursively, a quadtree data structure is used. Quadtrees can be used to depict a hierarchical decomposition of the geographical area. After that, to search the intersection between the quadtree and the destination area, a tree pruning approach is proposed. On the basis of the quadtree model, an election technique is utilized to choose the optimum Road Side Unit (RSU) to forward the data packet towards the destination region.

In Vehicular Ad-hoc Networks, geocasting is very important for many different types of applications which require transmission of data packets from a source node to a particular geographical region. Some of the most common examples of such applications include geographic advertising, accident warning, weather updates, alternative route suggestions, and so on. Therefore, it is essential that the vehicular networking environments which deploy such applications require geocasting protocols to be designed to be very reliable and also efficient.

Most of the geocast protocols applied to vehicular networking environments fall into either of the two categories, which are, flooding approaches and non-flooding approaches [21].

Nevertheless, neither of these approaches is appropriate for vehicular networking environments because of the following major reasons:

1. The flooding approaches can cause tremendous overheads in vehicular networking environments if the mobility patterns of the nodes and communication modes are not taken into consideration. The communication modes (i.e., vehicle-to-infrastructure (V2I) or vehicle-to-vehicle (V2V)) are very divergent from most of the other ad-hoc networks, and the vehicular movements have some definite patterns of mobility which should be regarded while designing communication protocols.

2. Non-flooding approaches, on the other hand, need a predetermined and fixed network and/or network topology information. But in vehicular networking environments such information is very difficult to aggregate mainly because of the highly dynamic nature of the nodes (i.e., vehicles) and consequent changes in the network topology.

3. None of the above two approaches takes into consideration the possible use of the Road Side Units (RSUs) to support the geocasting procedure, which can be much more productive and cost-efficient in vehicular networking environments.

In Vehicular Ad-hoc Networks, a vehicle may directly transmit data packets to another vehicle, if the other vehicle is within its transmission range, or otherwise through Road Side Units (RSUs). RSUs are equipped with wireless communication capabilities and resources for storing and forwarding data packets in the vehicular networking environments. They are placed alongside the routes of the vehicles and thereby are actively involved in the data exchange with the traffic that passes though the road near them. Therefore, these Road Side Units improve the connectivity in the region and help in the overall improvement of the vehicular network's performance.

Meanwhile, some approaches exist which exploit the concept of Road Side Unit assisted routing [22] or geocasting and the vehicle's mobility patterns. Also, considering vehicular movement patterns, the forwarding schemes can be much more efficient, for example, utilizing concepts such as social-aware mobility or trajectory-based mobility.

Nevertheless, protection of privacy of the users during the exchanging of trajectory information among the nodes (i.e., vehicles) is not taken into consideration by most of the trajectory-based approaches. Because of these privacy concerns, many nodes using RSU-assisted routing approaches do not disclose information about their destinations and trajectories to other vehicles. They prefer to disclose their trajectory information only to the traffic control center of the Road Side Units.

Furthermore, in real world scenarios, majority of the drivers may choose not to input their destination information in the cases where they happen to be acquainted with the streets and the highways. Owing to these factors, implementation of these previously noted approaches can be often problematic practical applications.

In Vehicular Ad-hoc Networks, the Road Side Units can be used for geocasting purposes because the delay involved in the transmission of the data packets through the fixed Road Side Unit network is very small as compared to sending the data packets through the vehicular nodes. Furthermore, considering the protection of the users' privacy, there is no requirement for the vehicles to input information related to their destination and/or trajectory. Only the Road Side Units need to be location aware. In this way, such approaches can be much easier to implement in practice.

The major propositions in the following section are as follows:

1. In order to represent a geographic area's hierarchical decomposition, a quadtree model based approach is proposed. The quadtree data structure is used to recursively represent the geographical region and it's Road Side Units for the purpose of routing in the vehicular networks.

2. After that, to obtain the intersection between the quadtree and the destination area, a tree pruning approach is proposed. By this process, we obtain the list of specific Road Side Units by pinpointing them within a geographic region, to which the data packets are then forwarded.

3.2 System Model and Problem Formulation

In the following segment, quadtree model, which is capable of representing the complete geographic area efficiently, is described. After that, the communication model is stated along with the problem formulation.

3.2.1 Assumptions

There are some assumption which have been made to implement the system. We presume that the Road Side Units have already been installed in advance. And also, these Road Side Units are connected to each other through wired communication links, which are essentially gateways incorporating the wired network and the vehicular network. Furthermore, every Road Side Unit is equipped with DSRC (Dedicated Short Range Communications), processing, and storage capabilities to send, receive, process, store, and forward data packets to nodes in the network.

It is assumed that the vehicles (i.e., nodes) are furnished with the OBUs (i.e., On Board Units). These On Board Units are utilized by the vehicles to exchange data packets with Road Side Units and other vehicles in the neighbourhood. As a consequence, there are two modes of communication in the vehicular networking environment:

1. Vehicle-to-RSU (V2R)
2. Vehicle-to-Vehicle (V2V)

As shown in the figure below, some Road Side Units are already deployed in the area, and a source vehicle, say S, desires to transmit a data packet to a particular vehicle in the dark shade circular region in the centre of the figure. This presents a problem regarding the procedure to transmit the data packet to the destination vehicle in an efficient way and as quickly as possible.

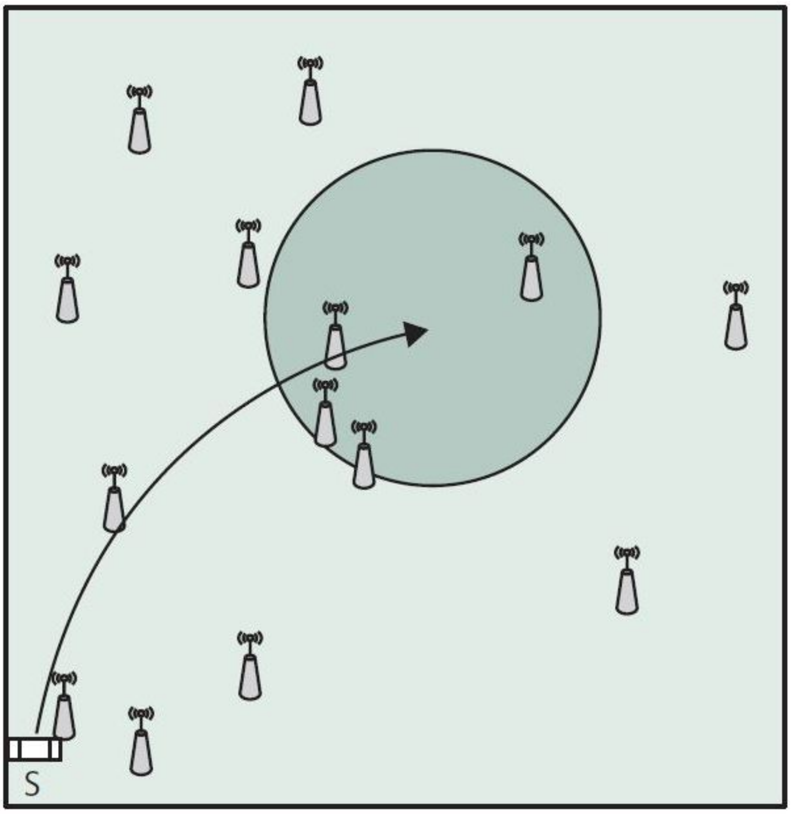

Figure 3.1 - The region area

To solve this problem, it is presumed that the region has an inherent division based on geographical position. It is not required that the region be uniformly divided, but be according to the inherent attributes of the geographical position. The more popular region will be further subdivide into smaller squares until there is only one or less Road Side Unit in the square. Therefore, the division granularity is little for some of more popular areas whereas larger for some less popular areas.

As shown in figure below, the previous region is recursively divided into squares. Each square can be further subdivided into four smaller squares if there is more than one Road Side Unit in the square. Every node representing a square has to only remember its immediate parent and its immediate children only for routing purposes. In this way we can represent the entire region starting from the root node. In the figure below, the southeastern corner of the global area is less popular, therefore it is not subdivided into smaller squares. In case there happens to be no deployed Road Side Unit in a region, then it will not be further subdivided.

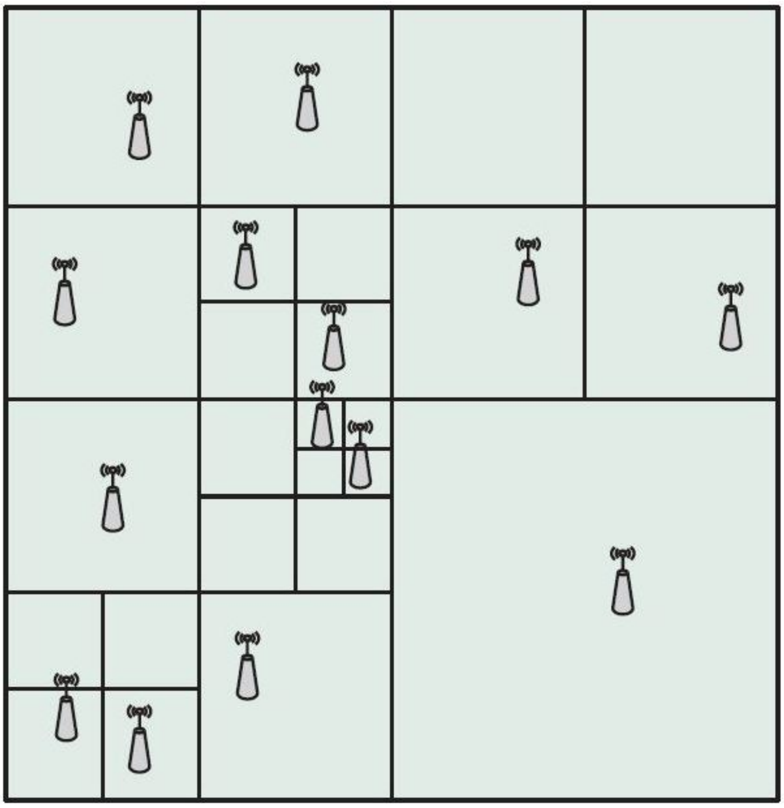

Figure 3.2 - The region division

3.2.2 Quadtree Model

A region quadtree represents a partition of 2-dimensional region by decomposing the given region into four equal quadrants, sub-quadrants, and so on with each leaf node containing data corresponding to a specific subregion. Each node in the tree either has exactly four children, or has no children (i.e., a leaf node). The height of quadtrees that follow this decomposition strategy (i.e. subdividing sub-quadrants as long as there is interesting data in the sub-quadrant for which more refinement is desired) is sensitive to and dependent on the spatial distribution of interesting areas in the space being decomposed. The region quadtree is a type of trie [23] [24] [25].

To efficiently represent a geographic region, a quadtree model is used. A quadtree T represents a 2-dimensional geographic region. The root represents the entire region, and has 4 children. The 4 children are clockwise to the four subregions, respectively. Each child of the node is either a sub-quadtree or a leaf.

Different colors for representation of the different regions, in order to describe the quadtree structure. As depicted in figure below, red is used to refer to the first level of the four nodes. The root has four red children in the quadtree. Then green is used to refer to the second level of nodes. Note that the southeastern corner of the region is not divided into a sub-region, so it does not have a child. In the third level, blue is used, and it can be observed that there are only three regions that have been divided into sub-regions. In the end, yellow color is used to refer to the fourth level of nodes.

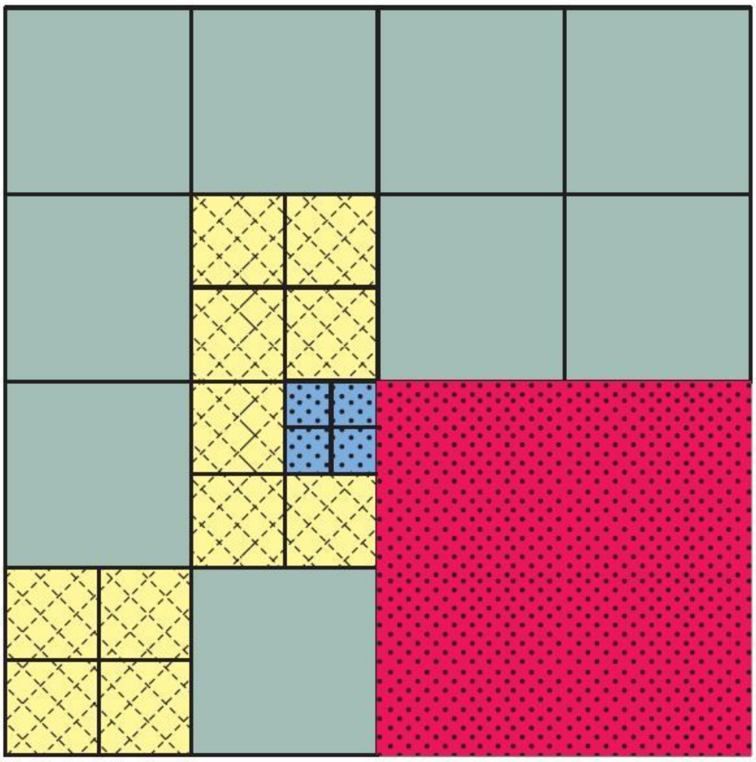

Figure 3.3 - The region graph

Therefore, a quadtree is constructed, as shown in the figure below, to represent the entire geographical region. Note that, it is not ensured that each region has a Road Side Unit. The Road Side Units only need to be aware of their own regions. They do not have to know their parent region division. If there is no Road Side Unit in some region, the region must be a leaf node. Thus, for all non-leaf nodes of the region, there must be an Road Side Unit. We assume that each Road Side Unit has a unique identification number. For all the non-leaf nodes, we select a gateway Road Side Unit to represent the non-leaf node.

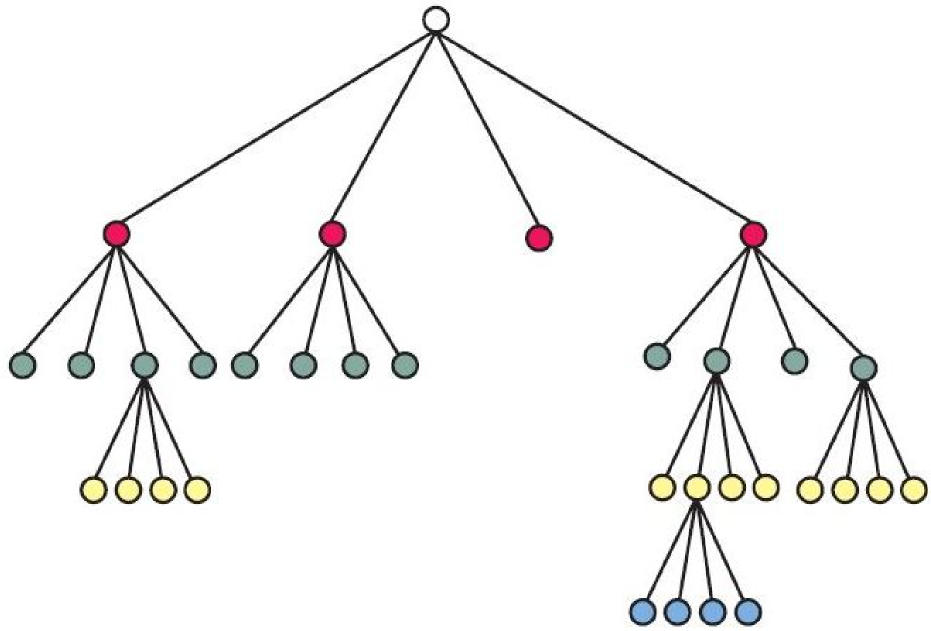

Figure 3.4 - The Quadtree

3.2.3 Vehicle to Road Side Unit Communication Model

Since the geocast proposed is an on-demand based type of protocol, therefore, to decrease the overhead on the system, it is not required for each node to transmit hello packets periodically to the neighbours.. It is presumed that the Road Side Units communicate with the vehicles only when the vehicles are in the range of transmission of the Road Side Unit.

Therefore, when vehicle meets a Road Side Unit, it sends a hello packet to the RSU containing its unique ID. The RSU then records the ID of the vehicle and the current timestamp of the encounter and stores these details in a centralized database. The stored record can be used to know the region where the vehicle was last seen, and this information can then be used to target the geographical area where the vehicle may next be available for communication. We use the recorded details to pinpoint the Road Side Unit that encountered the vehicle for the last time, and using the location of that Road Side Unit, we find out the probable area in which the vehicle might be based on the speed limit of the traffic system and the timestamp of the last encounter. In this way, we know the geographic region inside which the vehicle is still most likely to be present. Therefore, using the Quadtree pruning approach, we can now find out the specific Road Side Units to which the packet needs to be forwarded to reach the vehicle. All these Road Side Units, on receiving the packet, store it in their buffer until they encounter the aforementioned vehicle or until their buffer becomes full, in which case they discard the packet.

Chapter 4

IMPLEMENTATION

4.1 Overview

The geocasting approach has the following three important steps to deliver a packet from a node to another node present in a specific geographic region:

1. The source node transmits the packet to its nearest Road Side Unit.
2. The nearby Road Side Unit receives the packet, then it transmits the packet to the destination Road Side Unit.
3. The destination Road Side Unit sends the packet to the destination vehicles.

4.2 Algorithms

Quadtree Insertion: Given a valid quadtree, a new vertex is inserted into the existing node structure in the following manner:

1. If the quadtree has no root node, place the new vertex at the root node and exit. Otherwise, start the current node at the root.
2. Find the direction from the current vertex to the new vertex.
3. If the current node has no child in that direction, make a new child node there with the new vertex and exit.
4. Let the current node's child in that direction become the current node, and repeat.

Thus, the time to insert a vertex is bounded by the maximum depth of the quadtree.

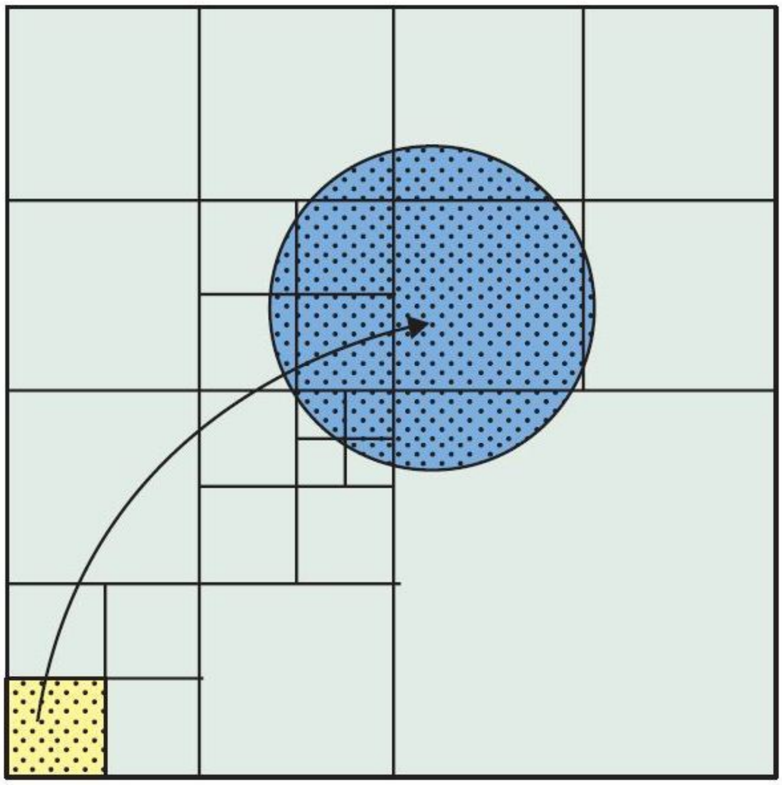

Figure 4.1 - An example of intersection region and quadtree

Quadtree Pruning: Algorithm describing the pruning process is as follows:

Algorithm: **Prune(C, R, T)**:

Input: an input of circle of radius r, a node R in T, and a rectangular-decomposition-tree T;

If $R \cap C = \phi$, then return ϕ;

If $R \subseteq C$, then return {R};

else

If R has children R_1, R_2, R_3, R_4,

then return Prune(C, R_1, T) ∪ Prune(C, R_2, T) ∪ Prune(C, R_3, T) ∪ Prune(C, R_4, T);

else return {R} (R is a leaf);

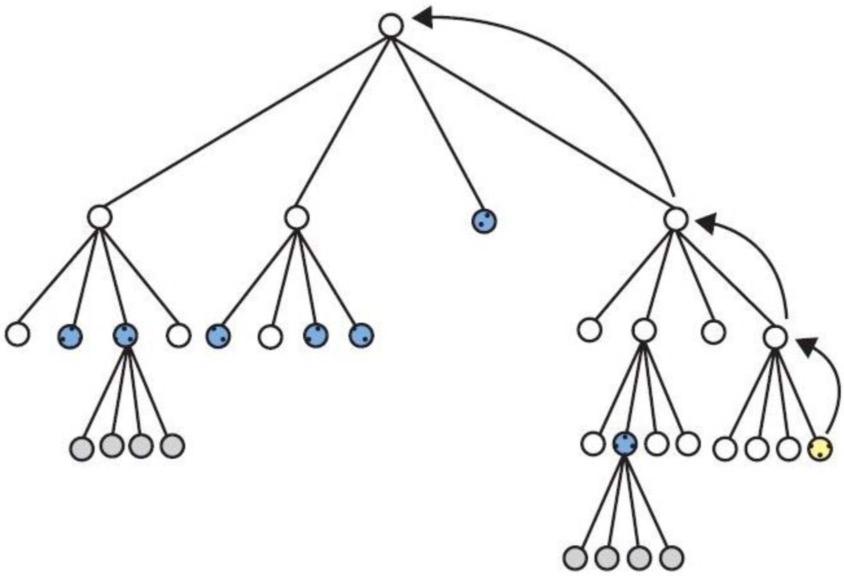

Figure 4.2 - The intersection nodes of quadtree

Chapter 5

RESULTS AND ANALYSIS

5.1 Results

The proposed framework was implemented and simulated in Java. The roadside units were generated randomly on a square geographical region of area 64 square kilometers. The results were generated for two particular metrics: the number or roadside units and the transmission range of the roadside units. The results were produced by running 500 test cases with different parameters.

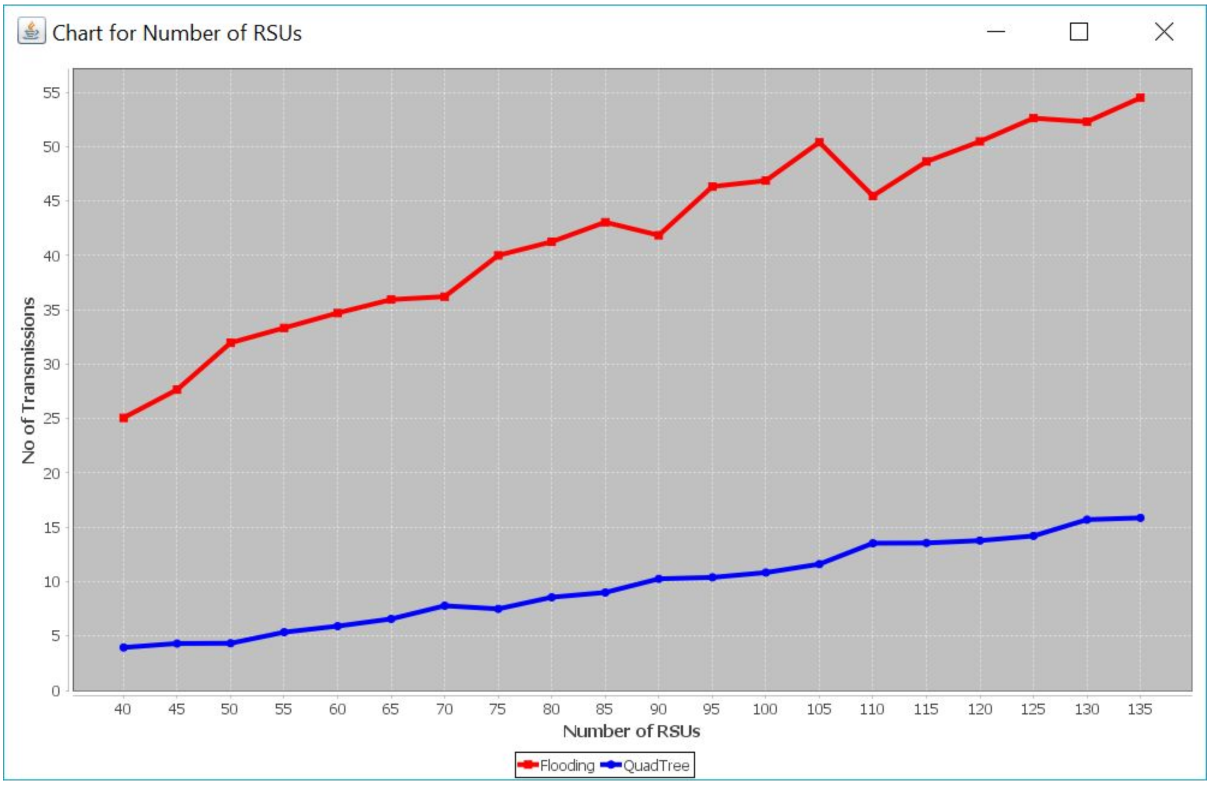

Figure 5.1 - Result graph for different number of Road Side Units (RSUs)

The above figure is a graph depicting results for test cases where roadside units are increased from 40, initially, to 135 in the final test case. The transmission range is set to be a constant 5 kilometers.

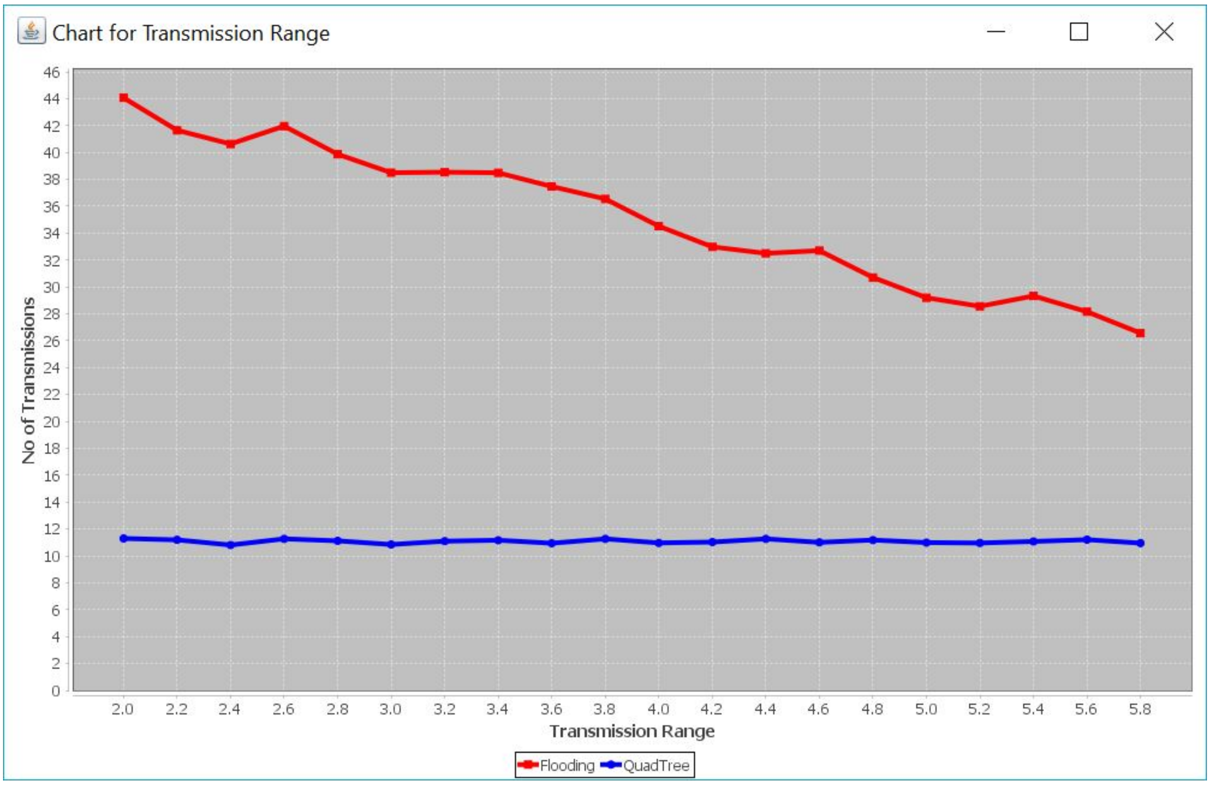

Figure 5.2 - Result graph for different Transmission ranges

The above figure represents the graph for results derived by running test cases for different transmission ranges from 2 kilometers to 5.8 kilometers. The number of Road Side Units (RSUs) is set to be a constant 50 in the geographical area.

5.2 Analysis

The results depict the theorized difference between flooding based protocols and the proposed quadtree based approach. As is evident from the first graph, the cost of delivery, i.e. the number of transmissions, increases drastically with the increase in the number of Road Side Units (RSUs) deployed in the region. This is because of the high number of data packets generated for the increasing number of additional network nodes in the vehicular network. In comparison to the flooding based techniques, the cost of delivery increases at a much lower rate for the proposed quadtree based approach.

In the second graph, it can be observed that that the performance of the flooding based techniques improves as the transmission range increases, but even then it is not as favourable as the quadtree based approach, which comes out on the top.

It can be concluded from the above two graphs that the quadtree based approach is generally more efficient as compared to the flooding based techniques, as it tries to structure a geographical region into logical divisions and use those logical divisions for implementing a protocol that uses up resources at a much lower rate.

Chapter 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

The framework proposed in this thesis incorporates two very important features into the Vehicular networking, which are the use of roadside units for assistance in routing and division of the geographical area into nodes of a quadtree which can be easily stored and managed. The utility of this system lies in the fact that it does not require the vehicles on the road to have been equipped with a Global Positioning System. It makes use of the positions of the roadside units for this purpose. And also, the system does not need to make use of flooding or flooding-based techniques to find a route to the destination vehicle. This feature, in particular, reduces the congestion on the network traffic which would in other case be high due to high number of packets in the network as a result of route discovery by flooding based techniques. The protocol is easier to implement because it enforces no conditions on the requirements for the communication capabilities of the vehicles on the road. All the required conditions are set for the roadside units. This makes it very simple to configure the infrastructure in a way that is feasible for the vehicular communication with most of the vehicles equipped with networking devices.

6.2 Limitations

As we all know that the vehicle will ultimately will ultimately be subject to the will of the driver, for the foreseeable future, therefore the delivery of the packet very much also depends on the decisions made by the driver while on the road. The protocol tries its best to find the most cost effective route, but it can only work if the on ground infrastructure is properly planned and implemented. For example, it cannot deliver a message if the vehicle turns of its communication facilities, or if the coverage of the network is very poor.

6.3 Future Scope

The proposed framework can be further integrated with topology data of the geographical area to enhance the prediction of the next possible destination of the vehicle and predict the time of arrival of the vehicle at the next destination. Such an integration would require the pre-built accurate data about the geographical topology of the area, which must be constantly be updated to account for any changes in the traffic conditions on the road. Furthermore, some of the clustering techniques can be applied on the network traffic to enhance the Vehicle-2-Vehicle communication when there is no roadside unit nearby. This could improve the poor network connectivity in certain regions.

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