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지도교수　모 상 만

이 논문을 공학석사학위신청 논문으로 제출함.

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컴퓨터공학과

Raj K. Shrestha

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ABSTRACT

A Vertex Based Predictive Greedy Routing Protocol for Vehicular Ad Hoc Networks

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Multi-hop data delivery in vehicular ad hoc networks (VANETs) is suffered by the fact that vehicles are highly mobile and inter-vehicle links are frequently disconnected. In such networks, for efficient multi-hop routing of road safety information (e.g. road accident and emergency messages) to the area of interest, reliable communication and fast delivery with minimum delay are mandatory. This research proposes the Vertex Based Predictive Greedy Routing (VPGR) protocol which predicts a sequence of valid vertices (junctions) from a source vehicle to a fixed infrastructure (or a roadside unit) at the area of interest and, then, forwards data to the fixed infrastructure through the sequence of vertices in urban environments. For forwarding data from the source vehicle to the fixed infrastructure in multi-hop fashion, the well-known predictive directional greedy routing mechanism is used. The proposed algorithm leverages the geographic position, velocity, direction and acceleration of vehicles for both the calculation of a sequence of valid vertices and the predictive directional greedy routing. Simulation results show significant performance improvement compared to conventional routing

protocols in terms of packet delivery ratio, end-to-end delay, and routing overhead.

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Acronyms

AODV	Ad hoc On-demand Distance Vector
AP	Access Point
A-STAR	Anchor-Based Street and Traffic Aware Routing
CAR	Connectivity Aware Routing
DSRC	Dedicated Short Range Communication
GeOpps	Geographical Opportunistic Routing
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
GSR	Geographic Source Routing
GyTAR	Improved Greedy Traffic Aware Routing
MANET	Mobile Ad Hoc Network
MOPR	Movement Prediction Based Routing
MANET	Mobile Ad Hoc Network
MOVE	Motion Vector
NS	Network Simulator
PDGR	Predictive Directional Greedy Routing
PBR	Prediction Based Routing
QoS	Quality of Service
RI	Routing Information
RT	Remaining Time
SAR	Spatially Aware Routing

TTL	Time-To-Live
VANET	Vehicular Ad Hoc Network
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
VPGR	Vertex-based predictive greedy routing
VVR	Virtual Vertex Routing

I. Introduction

A. Research Overview

Automotive industries and research institutions are envisioning the large application areas that running upon the VANETs, extending from co-operative driver assistance systems for collision avoidance, to notification of traffic condition on the road, parking availability and infotainment services. In [2], VANETs applications are classified into two categories: (i) those that require broadcasting of information from one vehicle to many nearby vehicles, e.g., for collision avoidance, and (ii) those that require the propagation of information hop-by-hop to a single destination point or area, e.g., for sending an emergency messages from an accident site to the closest roadside unit or fixed infrastructure that is connected to a fixed network, or for sending an advertisement from an attraction site to a busy intersection. The proposed new routing protocol for VANETs is focuses on the latter applications. We can assume that every vehicle is equipped with sensing, computing and radio communication devices. The sensing devices or sensor detects road conditions (e.g., accident) and traffic congestion. On detection of such events, vehicles can notify to the centralized unit or to access point (AP) by sending the sensed data regarding to the event.

VANETs are characterized mainly by highly mobile vehicles, resulting in frequent topology changes and short connection time in multi-hop paths. Furthermore, wireless communication is unreliable in V2V communications due to multi-path fading, shadowing, and Doppler shifts caused by the high mobility of vehicles. Such effects make routing quite complicated.

Routing protocol for mobile ad hoc networks (MANETs) are categorized into topology based ones and location (or) position based ones. In VANETs, Position based routing protocols outperforms topology based ones, because they only need the position information of participating vehicle to make routing decision. Consequently, they can include velocity, direction and acceleration of vehicle along with the position information to design QoS routing protocol. There are several existing routing protocols for VANETs even though they have some limitations and drawbacks. We believe understanding such limitations and drawbacks would be helpful to propose new routing protocol with better performance than existing one.

That is why we focus our research in two parts. Firstly, covers the complete survey and analysis of existing routing protocols for vehicular ad hoc networks (VANETs) and compare them in terms of their characteristics, performance and focused applications. Secondly, we solve the some of the limitation and issues in existing one and propose new geographic position-based routing protocol for VANETs, so-called *vertex-based predictive greedy routing (VPGR)* protocol. The proposed routing protocol performs mainly two operations: (i) prediction of sequence of valid vertices between source vehicle and nearest access point (AP) or infrastructure from the source vehicle, (ii) forwarding of data between source vehicle and nearest AP using well-known predictive directional greedy routing through the sequence of predicted valid vertices.

Prediction of sequence of vertices (or junctions) combined with well-known predictive greedy forwarding for forwarding of data from source vehicle to the fixed infrastructure. This scheme minimizes the re-transmission of data and, hence, minimizes consumption of unnecessary channel bandwidth and delay as well. This research work proposes a geographic prediction based routing for VANETs called Vertex-based Predictive Greedy Routing (VPGR). It predicts a sequence of vertices from a source vehicle to a fixed infrastructure (or a roadside unit) at the area of interest and, then, forwards data to the fixed infrastructure using well-known predictive greedy forwarding mechanism through the sequence of vertices in the city environments.

B. Research Objectives

The wide range of applications that may be running on a VANET in the near future suggests that they will be competing for the use of the wireless medium. Network resources will be shared by applications that provide internet access to passengers, propagate advertisement about nearby places of interest, and provide the driver with safety information (e.g. emergency messages, and collision avoidance messages) and so on. In such emergency messages, there should be very minimum delay. For dissemination of safety information, low latency of 100 milliseconds should be guaranteed [5]. Here we are considering a densely populated city area where generally the wireless medium is shared by a large number of vehicles.

On the other hand, due to the characteristics like highly mobile vehicles, like breakage between vehicles is inevitable. Therefore, sending packet may be lost due to frequent link breakage and re-transmission of packet is required, which consumes unnecessary channel bandwidth. The major objective of this carried research is to study the limitations and issues in VANETs routing protocols and to suggest some techniques and algorithms which could improve the performance in terms of packet delivery ratio, end-to-end delay and routing overhead.

C. Thesis Contributions

The proposed VPGR protocol takes the advantages of prediction of sequence of vertices and for forwarding data from source to destination through sequence of valid vertices using well-known predictive directional greedy routing technique to results in more efficient and reliable routing. These schemes minimize the re-transmission of data and, hence, minimize consumption of unnecessary channel bandwidth and delay as well. The main contributions of the thesis are as follows:

- Proposition of vertex-based predictive greedy routing (VPGR) protocol based on prediction technique. Such a prediction leverages the useful knowledge of future network conditions.

- VPGR always forwards packets through a sequence of valid vertices or junctions because of this no risk of packet loss due to wireless medium obstacle at the junction in the city environments.
- VPGR saves channel bandwidth, reduces packet re-transmissions, increases reliability of packet delivery, and minimizes end-to-end delay.

D. Thesis Organization

The remainder of this thesis is organized in modular chapters. Chapter 2 overviews vehicular ad hoc network (VANET) and VANET routing strategies found in the literature. The system model, assumptions, and objectives of the work are outlined in chapter 3. In chapter 4, the proposed vertex based predictive greedy routing (VPGR) is presented. Chapter 5 discusses the performance evaluation of the proposed routing protocol. The mobility model, simulation environment, and simulation results are presented in detail. This thesis is concluded in the last chapter with the wrapping text for summary of this research.

II. Vehicular Ad Hoc Networks and Routing

Vehicular ad hoc networks (VANETs) are a practical application class of mobile ad hoc networks (MANETs), where multi-hop paradigm is successfully applied in pragmatic way to extend the internet and/or to support well defined requirements [1]. They are a distributed and self organizing communication system which is composed of moving vehicles equipped with sensing, computing and radio communication devices to form temporary communication networks with or without help of any infrastructure (or roadside unit). Vehicles can exchange road safety and comfort information with other vehicles (so-called vehicle-to-vehicle or V2V communication) as well as with infrastructure (so-called vehicle to infrastructure or V2I communication) within their communication range. In addition, individual vehicles are responsible for routing the packets with allowable delay.

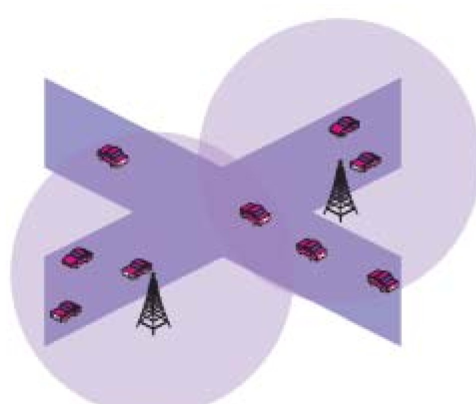

Figure 2-1: Vehicle-to-infrastructure (V2I) communication

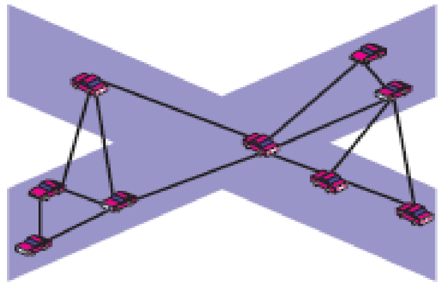

Figure 2-2: Vehicle-to-vehicle (V2V) communication

A. Key Properties of VANETs

A VANET is an instantaneous and challenging class of MANETs. It behaves as a MANET and shares different MANET properties. However, properties like driver behavior, mobility constraints and high mobility of vehicles cause frequent link breakage and long latency, which lead some differences from MANETs:

- *Network topology*: Due to the high speed of vehicles, the network topology changes very frequently. It could be affected by driver's behavior as well [4].

- *Network density and variability*: The network density directly depends on the number of vehicles in a particular location and can be varied at different time, road condition, etc.

- *Connectivity and low latency*: Vehicles can join and leave the network in very short time leading to frequent network partitioning. Such a partitioning reduces the lifetime of routes. For dissemination of safety information, low latency of 100 milliseconds should be guaranteed [5].

• *Energy and processing capacity*: VANET nodes (vehicles) have powerful and rechargeable energy source and high processing capacity.

• *Displacement environment*: Vehicles are constrained to move within the road infrastructures such as highway and city roads. Moreover, the constraint imposed by the environment (e.g., buildings) affect the quality of radio transmission.

B. Issues in Routing

A VANET is a distributed and temporary communication system formed by a number of vehicles without any infrastructure and, thus, the routing in a VANET relies on vehicles that have unique properties such as high mobility. The frequent topology changes and mobility constraints cause the challenges in routing. Following issues may be considerable for reliable and efficient routing while designing new routing protocols:

• *Connectivity of link*: Vehicles can leave and join another network in very short time. This may cause frequent link breakage and resulting route failure. Therefore, the reliability of links might be the important issue.

• *Latency*: The interest and popularity of VANET are growing because of driver safety and other infotainment applications. The U.S. Department of Transportation's vehicle safety communication project defines 100 milliseconds of latency for the requirements for safety applications [5].

- *Obstacle*: In the city roads, high buildings are the radio obstacle for the dedicated short range communication (DSRC) wireless channel, and the transmission may be failed in such situations.

- *QoS*: Only the position information of vehicles is not sufficient for QoS routing protocol but also other parameters such as the movement direction of vehicles, velocity, and acceleration are issues for efficient routing.

C. Related Work

The conventional *topology-based routing* protocols need to maintain global routing information of a network. Since the high mobility of vehicles leads to frequent topology change and link breakage, the topology-based routing protocols are not suitable for VANETs. On the other hand, the *position-based routing* (*PBR*) protocols are reliable and efficient for the vehicular environment that requires position information about geographic position of participating nodes. The position information of nodes can be obtained from global positioning system (GPS) or location service schemes [6]. The PBR protocols consist of *location service* which maps node id to geographical position and *forwarding schemes* which selects the next hop neighbor based on geographical information of the node, neighbors and destination to forward the data [7].

In this section, we review and compare the existing routing protocols proposed so far for VANETs in the literatures. For the systematic classification of various routing protocols, we categorize them into three domains of geographic forwarding based routing protocols, trajectory forwarding based routing protocols and opportunistic forwarding based routing protocols on the basis of the forwarding schemes as in [4].

1. Geographic Forwarding Based Routing Protocols

In these protocols, the geographic position of nodes is necessary to forward the packet in a greedy way to the neighbor which is geographically closest to the destination. If the node (which contains the packet to be forwarded) does not find the neighbor closer to the destination than itself within its radio range, the greedy algorithm may fail.

Greedy Perimeter Stateless Routing (GPSR):

GPSR [8] combines greedy forwarding on full network graph with perimeter forwarding using planar graph traversal where greedy forwarding is not possible. The planar graph is a graph with no intersection between any two edges. The graph formed by an ad hoc network is generally not a planar graph. It is important to know that the decision as to whether an edge is within the planar sub graph can be made locally by each node, since each node knows the position of all its neighbors [9]. When packet reaches a location closer than where the greedy forwarding is previously failed, the packet successively continue greedy progress toward the destination without the risk of local maximum.

Geographic Source Routing (GSR):

GSR [9] combines PBR with topological knowledge of the road; it is obtained from a navigation system. It uses reactive location service (RLS) to know the current position of the desired communication partner. When the querying node requires position information of neighboring nodes, it floods the '*position request*' containing its id to the network in reactive way. When the corresponding node receives the request, it sends '*position reply*' to the querying node. With the position information of neighbor nodes, the sender node computes a sequence of junctions, through which a packet has to traverse to reach its destination using city map. Note that the sequence of junctions can be either contained in the packet header or computed by each forwarding node [9]. Forwarding a packet to successive junctions is done on the basis of greedy forwarding and using Dijkstra's shortest path algorithm, and the distance from source to destination can be calculated based on the city map. When a route break occurs, GSR uses the recovery strategy '*fall back on greedy mode*' to bypass the particular node.

Virtual Vertex Routing (VVR):

VVR [10] uses the line information (i.e. roads, rails and courses) of each vehicle, which is provided by navigation system or digital road map equipped in vehicles. It forwards packet in greedy way to the intermediate nodes and solves the so-called *routing hole problem*. If the node density is high enough, routing holes occur rarely and geographic routing is effective [11]. However, it is claimed in [10] that the node density is much more dependent on the layout of lines. So, the high node density does not help to solve the routing hole problem if all the vehicles lie on a specific line. VVR represents the network as a graph and uses the concept of *virtual vertex* (i.e., the adjacent crossing point of two vertices). The intermediate nodes in the proximity of vertex perform routing towards destination using Floyd algorithm. To tackle the routing hole problem, VVR–greedy routing (VVR-GR) and VVR-face routing (VVR-FR) schemes are proposed as well [10]. VVR-GR reduces the recovery time of routing holes and VVR-FR can guarantee the delivery of packets.

Improved Greedy Traffic Aware Routing Protocol (GyTAR):

GyTAR [12] is an improved greedy traffic aware, intersection-based geographic routing protocol which uses real-time traffic density information and movement prediction to route packets. It consists of two modules of (i) selection of junctions through which a packet must pass to reach its destination and (ii) an improved greedy forwarding mechanism between two junctions [12]. When a vehicle receives a packet, it computes its next junction with the highest score by considering traffic density and curve-metric distance to the destination. The junction with the highest score is geographically closest to the destination vehicle and has the highest vehicular traffic. Between two adjacent junctions, the packets are forwarded through the vehicles on between the successive junctions by using improved greedy forwarding. Each vehicle maintains a table containing position, velocity and direction of each neighboring vehicles, and the table is updated by periodically exchanging HELLO messages among vehicles. Using the information in the table, forwarding vehicles select their next hop neighbor which is closest to the destination junction.

2. Trajectory Forwarding Based Routing Protocols

In these protocols, messages are directed along with the predefined trajectory or path. The performance of these routing protocols is satisfactory even in the network with sparseness condition. The forwarding trajectory is an extended path from source to destination and helps to limit data propagation and, thus, it reduces message overhead and no end-to-end connectivity is assumed.

Connectivity Aware Routing (CAR):

CAR [13] finds a connected path between source and destination and maintains it permanently. CAR uses adaptive beaconing mechanism containing velocity vector of vehicles. Every node updates its neighbor table containing sender of beacons, sets its own and neighbors' velocity vector, and sets the expiration time for an entry in the table. In CAR, two type of guards are defined: *standing guard* and *traveling guard*. The standing guard gives geographic area information of nodes and the traveling guard contains velocity vector. Preferred group broadcasting in data dissemination mode helps to find destination and a path to it. If two velocity vectors are almost parallel with a very small angle between them, the two vehicles can serve as a relay of the packet to destination each other. If the direction of two velocity vectors is different, the node adds an anchor to a broadcast packet. When several path discovery requests are received, the destination chooses a path with better connectivity and lower delay [13]. CAR uses mechanism of advanced greedy forwarding and forwards packet to the neighbor closest to the next anchor point. CAR handles routing errors using two mechanisms of timeout algorithm with active waiting and cycle walk around error recovery.

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

A-STAR [14] uses spatial information of street map to compute the sequence of anchor or junction with less weight. The weight can be assigned to each street based on density of vehicles in the street. Note here that low weight represents high density or traffic and vice versa. This uses static information but the real traffic information is needed. So, it is required that the weight of each anchor is recomputed from map information, resulting in the so-called *dynamic rated map* [14]. The street at which local maximum occurred is marked by ‘out of service’ temporarily, and this information is distributed to the network by piggybacking them into the packet to be recovered and prevents traversing through the anchor at which local maxim occurred.

Spatially Aware Routing (SAR):

SAR [15] uses a spatial model to predict and avoid forwarding failures due to permanent topology holes. Using the spatial model called parser proposed in [16], the topology information of roads can be extracted from a digital road map in geographic data format (GDF). Spatial model is based on the extracted topology information, which is known as graph spatial model $G(E,V)$ consists of a set V of vertices and a set E of edges. SAR consists of *geographic source route* (*GSR*) and GSR-based packet forwarding. In the spatial model, a source vehicle calculates the shortest path P to the destination using the shortest path algorithm. Then, the source vehicle sets GSR to *P* consisting of intermediate vertices. In the GSR-based forwarding, all data packets are marked by source, destination and intermediate vehicles along with GSR. When a forwarding vehicle finds the vertex to be located within its radio, that vertex will be removed from the GSR and packets will be forwarded to the next vertex of the GSR.

3. Opportunistic Forwarding Based Routing Protocols

In these protocols, data packets are stored and forwarded opportunistically. When a packet is forwarded to an intermediate node, a copy of the packet may remain with the transmitting vehicle, which may be forwarded later again to improve reliability. Note that no end-to-end path can be assumed in these protocols.

Geographical Opportunistic Routing (GeOpps):

In GeOpps [17], each vehicle calculates its suggested route and the estimated time of arrival (ETA) of vehicles to the destination is calculated using the information contained in the navigation system. When a vehicle gets a packet, it calculates the nearest point (NP) to reach the destination from its suggested route. If the vehicle (with the packet to be forwarded) encounters one or more vehicles in its suggested route, it uses *utility function* to calculate the minimum estimated time of delivery (METD) of packet through the neighbor vehicles and itself using map information. Therefore, METD = ETA to NP + ETA from NP to

D. Then, the intermediate forwarding vehicle forwards packets to the vehicle with the lowest METD value.

Mobility Centric Data Dissemination Algorithm (MDDV):

MDDV [18] combines the idea of geographic forwarding, trajectory forwarding and opportunistic forwarding. A road network can be assumed as a directed graph, where nodes represent intersections, edges represent road segments and geographic distance can be obtain. A forwarding trajectory is a path extending from source to destination with the smallest sum of weights in the weighted road graph. Dissemination length is the lowest weight from source to destination in the weighted graph. The dissemination length of road segment is used as the weight for the link in a road graph. Dissemination process consists of forwarding phase and propagation phase. A message is forwarded through intermediate nodes and the node which holds message is known as *message head*. To increase reliability, MDDV forwards messages to the set of nodes around the message head. Vehicles store messages until memory buffer is full and drop the packet when they leave passive state during the forwarding phase and leaves active state during the propagation phase.

Movement Prediction Based Routing (MOPR):

MOPR [19] takes into account of position, direction and speed of vehicles to predict vehicles' future position and size of data to send. It uses *stable route* in which intermediate nodes are moving in similar direction and speed with respect to source and destination vehicles. If transmission starts at t_0 and time needed to transmit data is T, MOPR first estimates the position of vehicles at time $t_0 + T$. Then, it estimates the distance at time $t_0 + T$ taking into account a processing time between each node and its neighbors in the route. If this distance is longer than the communication radio range, then the route is not considered as stable. It avoids link ruptures so the frame loss rate is reduced while improving the network efficiency by predicting future nodes' positions.

Prediction Based Routing (PBR):

PBR [20] uses predictable motion of vehicles along with readily available location and velocity information of vehicles to predict route lifetimes to create new route before existing one fails. The link formed by the vehicles moving in same direction has longer duration than that moving in opposite direction. To establish a route, a source node broadcasts route request (RREQ) packet with a time to live (TTL) value specifying the number of hops to search for a gateway that would have the required route. If the source gets multiple routes for the same gateway, it chooses the route with the maximum predicted route lifetime. Based on the velocity and location information of predecessor available in route response (RREP) packet and those of itself, all the intermediate nodes predict the lifetime of the link between the two nodes using the prediction algorithm: $lifetime_{link} = R - |d_{ij}| / |v_i - v_j|$, where R is the communication range, $|d_{ij}|$ is the absolute distance between two nodes i and j, and v_i and v_j are the corresponding velocities of nodes i and j.

Motion Vector (MOVE):

MOVE [21] uses velocity information to make forwarding decisions. In MOVE, vehicles are used as mobile routers to collect and deliver a data between static nodes (road side sensors and a central server). A message is cached for an arbitrary amount of time at the mobile carrier or intermediate static node. The destination node is static and its position is known globally throughout the network. MOVE leverages the knowledge of relative velocities of a mobile router and its neighboring nodes to predict the closest distance to the destination. In [24], authors described different ways of determining the closest distance and rules for making forwarding decisions in the MOVE algorithm.

D. Comparison

In Table 2-1, the different routing protocols discussed earlier are compared in terms of their characteristics, performance and application domains. In the geographic forwarding based routing protocols, GPSR is scalable under the increasing number of nodes but its overhead increases due to location registration and lookup traffic for location database. In GyTAR, the delivery ratio is not satisfactory whereas packets are delivered with lower end-to-end delay. In VVR, the packet delivery ratio is 100% and overhead remains constant as speed increases but the delay increases with increased speed.
In the trajectory forwarding based routing protocols, CAR outperforms other two routing protocols because its delivery ratio is improved and overhead is reduced with increased density. On the other hand, A-STAR improves the packet delivery ratio while maintaining the reasonable end-to-end delay.

In the opportunistic forwarding based routing protocols, MDDV, GeOpps and PBR give higher delivery ratio than the other protocols. MOPR significantly reduces the frame loss rate and MOVE can deliver packets with the minimum delay. In addition, MDDV supports all of the forwarding schemes.

Of all the routing protocols studied in this paper, VVR is the best one in terms of delivery ratio while MDDV should be the choice if the minimal overhead is the primary concern. Furthermore, it should be noticed that GPSR gives good scalability and GyTAR gives low end-to-end delay.

Table 2-1: Comparison of different routing protocols

Category	Routing protocol	Characteristics	Performance	Applications focused
Geographic forwarding	GPSR [8]	Uses planar graph traversal for packet forwarding in perimeter mode	Scalable under the increasing number of nodes and increasing mobility rate	Vehicular networks with frequent route failure
	GSR [9]	Combines position and topological information in routing decision	Performs well at the high mobility of nodes	City areas
	GyTAR [12]	Uses real time traffic information and movement prediction	Efficient usage of network resource and low end-to-end delay	City environments
	VVR [10]	Uses the proximity of vertex	Delivery ratio is 100% and routing overhead remains constant as speed increases.	Vehicular networks with frequent routing hole condition
Trajectory forwarding	SAPR [15]	Uses spatial model to predict and avoid forwarding failure	Significantly improves forwarding performance in situations with many permanent topology hole	City environments
	CAR [13]	Provides connectivity path between source and destination	High delivery ratio and low overhead even with increased density	Inter-vehicle communication in the city and on the highway
	A-STAR [14]	Uses spatial information for routing decisions and selects path with higher connectivity	Improves packet delivery while maintaining reasonable end-to-end delay Reduces end-to-end delay in packet delivery	Metropolis vehicular communications
Opportunistic forwarding	PBR [20]	Uses predicted route lifetime to create a new route before existing route fails	Significantly improves route failure, higher packet delivery ratio and control overhead	Highway areas
	GeOpps [17]	Uses concept of the nearest point and the estimated time of arrival to the destination	Delivery ratio is very high and the required minimum number of hops is constant with the increased number of vehicles.	Vehicular networks with constantly changing topology and no end-to-end connectivity
	MDDV [18]	Exploits vehicle mobility for data dissemination	Improves delivery efficiency but the overhead is similar to that of central intelligence scheme	Frequently partitioned and highly mobile vehicular networks
	MCPR [19]	Predicts future nodes position	Reduces frame loss rate	Reactive routing in VANETs
	MCVE [21]	Uses velocity information to make forwarding decision	Delivers data successfully with the minimal delay	Data collection and delivery between static nodes (roadside sensors a central server)

III. System Model

As an inherent characteristic, vehicles do not move randomly but they are restricted to move in the roads with the roadside unit at certain speed. This fact makes the prediction of the future network state including geographic position, speed and direction of vehicles relatively easier compared to the random mobility in general ad hoc networks. On the other hand, in city environments, high-rise buildings are the radio obstacles. In Figure 3-1, vehicle D is within the communication range of vehicle S. vehicle S forwards a packet to vehicle D, but vehicle D cannot receive the packet from vehicle S because of radio obstacles (high-rise buildings). In such an area, while greedy forwarding is used to forward a packet to its neighbor, source node (node and vehicle can be use alternatively) chooses a neighbor which is closest to the destination node within its communication range but the transmitted packet may be lost due to the radio obstacles. As a result, the packet is retransmitted, which consumes unnecessary channel bandwidth at the same time delay for packet delivery is also increases. Therefore, in city environments, the prediction of the future network state is very much important and the routing of packets based on the prediction mechanism should be a promising approach. Alternatively, prediction of vehicles near the vertex plays a vital role in VANETs especially in city environment.

This research work proposes a geographic prediction based routing for VANETs called Vertex Based Predictive Greedy Routing (VPGR). It predicts a sequence of vertices from a source vehicle to a fixed infrastructure (or a roadside unit) at the area of interest and, then, forwards data to the fixed infrastructure using well-known predictive directional greedy forwarding mechanism through the sequence of vertices in the city environments. This scheme minimizes the re-transmission of data and, hence, minimizes consumption of unnecessary channel bandwidth and delay as well.

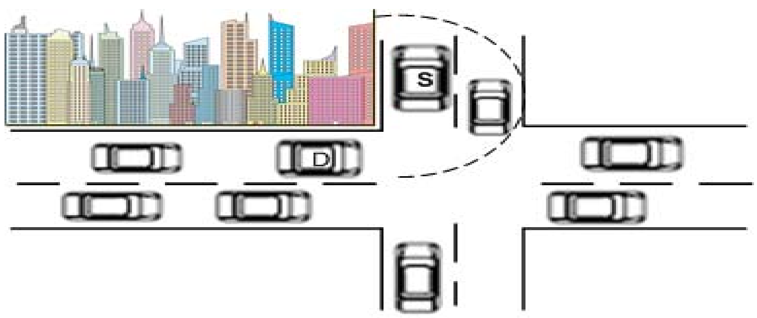

Figure 3-1: Effect of high-rise buildings in the V2V communication in city environment

We assume that each vehicle has a GPS receiver and is aware of its geographic position. Each vehicle knows the position of neighbors by hearing beacon messages that are periodically exchanged by vehicles and roadside infrastructure. The position of destination is obtained with the help of map information provided by the Navigation system. The map is abstracted as a directed graph *G (V, E)* where V is set of vertices and E is set of edges. The proliferation of applications that might be running on VANETs in the near future suggests that vehicles will be equipped with wireless transceiver and sensing devices. Using such devices, vehicles can communicated with neighboring vehicles or fixed infrastructures within the radio range. Fixed infrastructures are fixed roadside unit whose absolute location is known to all of the vehicles.

VANETs consist of hundreds or thousands of highly mobile vehicles, and a few number of fixed infrastructure or access points (APs). Upon sensing any event on the road, vehicles communicate in ad hoc manner among themselves to forward data from the source vehicle to the nearest AP. When a vehicle senses an event, it produces a message containing the event description and the entire event specific information such as message generation time (Tg) and time-to-live (TTL) value. The message is considered to be successfully delivered if it arrives at the nearest AP from the source vehicle before time *(Tg + TTL)* without any transmission error.

For the prediction of a sequence of vertices or junctions, a source vehicle identifies the number of involved junctions between the source vehicle and it's nearest AP. After that, remaining time *(RT)* of each involved vertices are calculated. *RT (i, j)* is a remaining time until a vehicle *i* remain within the threshold value *T* of a vertex *j*. For example, the threshold value T can be set to 100m from the center of vertex *j*. The vertex *j* is said to be valid if *RT (i, j) = {(Tg + TTL)/ 2}*. The calculation of *RT (i, j)* of any vertex j plays a significant role to make routing decision. *RT (i, j)* indicates whether the particular junction may provide connectivity for routing of data towards destination or not. If one of the vertices in its selected path is invalid, i.e. *RT (i, j) ≠ {(Tg + TTL)/ 2}*, then VPGR selects the next path to reach to the destination and follows the same procedure as discussed above for the calculation of *RT (i, j)*. If all the vertices are valid, i.e., *RT (i, j) = {(Tg + TTL)/ 2}*, the source vehicle forwards data through the sequence of vertices up to the fixed infrastructure in multi-hop fashion. For data forwarding, the conventional predictive directional greedy routing (PDGR) is used, where both position and direction of mobile vehicles are taken into consideration.

IV. Vertex Based Predictive Greedy Routing

In this section, the proposed Vertex Based Predictive Greedy Routing (VPGR) protocol is presented in detail. VPGR performs the two key operations of: (i) the predicting a sequence of vertices between source vehicle and destination, and (ii) the forwarding of data through the sequence of vertices by using the well-known predictive directional greedy routing (PDGR). For the prediction of a sequence of vertices, a source vehicle identifies the number of involved junctions between itself and nearest AP.

A. Prediction of Sequence of Vertices

For the prediction of sequence of valid vertices, a source vehicle calculates the shortest path between itself and its nearest AP with the help of city map information provided by the Navigation system. $RT(i, j)$ is calculated only for the vehicles within the threshold *T* from the center of vertex *j* and identifies whether a vertex is valid or not. The vertex *j* is said to be valid if $RT(i, j) = \{(T_g + TTL)/2\}$. The prediction of a sequence of vertices is done as followings:

Calculation of *RT (i, j)*

Notations:

$RT(i, j)$: a remaining time of vehicle i within threshold T of vertex j

T : Threshold of vertex j

$D(i, j)$: distance between node i within T and center of vertex j

Vi : velocity of vehicle i

$D(i, j) \le T$ and $t_1 < t_2$

Procedure:

if $D(i, j)_{t2} < D(i, j)_{t1}$

$$RT(i, j) = \{T + D(i, j)\} / Vi$$

else

$$RT(i, j) = \{T - D(i, j)\} / Vi$$

end if

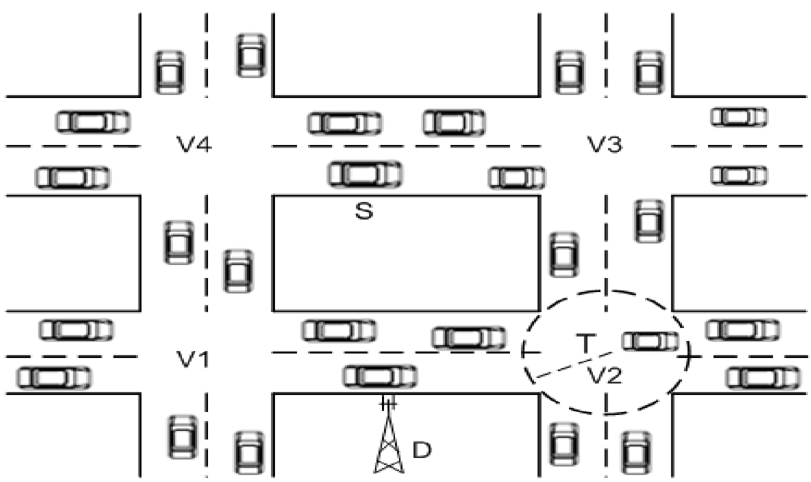

Figure 4-1: Selection of a sequence of vertices between a source vehicle and a fixed infrastructure or AP.

In Figure 2, let us suppose that the source vehicle *S* wishes to forward data to the nearest AP. The source vehicle *S* identifies a sequence of junctions (or vertices) between itself and the nearest AP, with the help of city map information provided by the Navigation system. The source vehicle *S* finds two routes to get to the destination, they are $S \rightarrow V_4 \rightarrow V_1 \rightarrow D$ and $S \rightarrow V_3 \rightarrow V_2 \rightarrow D$. The source vehicle always selects the shortest path between these two routes, with the help of the map information. The source vehicle S identifies the number of involved vertices within the shortest paths and calculates $RT(i, j)$ for each vertex (or junction). If $RT(i, j)$ of vertex is valid, i.e., $RT(i, j) = \{(T_g + TTL)/2\}$ then we can say that the junction can provide connectivity for packet delivery. In the selected shortest path, if $RT(i, j)$ of one of the vertices is invalid, then the source vehicle *S* chooses next route.

B. Predictive Directional Greedy Routing

Once the sequence of valid vertices between source vehicle *S* and access point (AP) are determined, the existing predictive directional greedy routing (PDGR) is used to forward data through the sequence of vertices from the source vehicle to the nearest AP. In PDGR, a forwarding vehicle calculates the weighted score not only for packet carrier and its current neighbors but also for its possible future neighbors (i.e., two-hop neighbors) in the very near future [3]. For the knowledge of the possible future neighbors, the packet requires two-hop neighbors' information, which is possible by exchanging beacon messages among them. For this procedure, all data packets are marked with the sequence of vertices in its packet header. Each vehicle maintains a neighbor table, which contains information about *node_id*, *position_of_node*, *velocity_of_node, acceleration_of_node* and *direction_of_node* of its neighbors. The neighbor table is updated by exchanging HELLO packets among neighboring vehicles. With the help of information contained in the neighbor table, a source vehicle calculates the weighted score not only for itself and current neighbors but also for possible two-hop neighbors. If a neighbor has the higher score than the current packet carrier, the source vehicle forwards the packet to the neighbor; otherwise, the neighbor carries the packet until it finds its neighbor which has higher weighted score than itself. The weighted score is calculated as in [3], i.e., $Wi = \alpha(1 - D_i / D_C) + \beta \cos(\vec{V}_i, \vec{P}_{i,d})$ Here, α and β are the weights for position and direction factors and $\alpha + \beta = 1$; D_i is the shortest distance from node to destination; D_C is the shortest distance from forwarding node to destination; D_i / D_C is the closeness of next candidate hop, $\vec{V}_i$ is the velocity vector of node *i;* $\vec{P}_{i,d}$ is the vector from the position of node *i* to the position of destination, $\beta \cos(\vec{V}_i, \vec{P}_{i,d})$ is the cosine value for the angel made by these two vectors.

1. Greedy Routing

Greedy forwarding reduces end-to-end delay and the number of hops, but in some cases, it may suffer from topology hole [15]; it is the situation when a data packet reaches a host that does not have any neighbor closer than itself to the destination. In [3], authors have presented two problems as shown in Figure 4-2 and Figure 4-3. In the figure, an incomplete broken circular line indicates transmission range of node A. Figure 4-2 shows routing loop problem in position first forwarding. When node A wishes to forward data to destination D at time t1, A forwards the data to B because B is closer to the destination than A. Unfortunately, B cannot transmit directly to D because D is not within B’s communication range. At time t2, B forwards the same data to A. in such scenarios, greedy routing may suffer from routing loop. Figure 4-3 shows an unreliable neighbor selection problem in direction first forwarding. Two nodes A and B are moving towards the destination node D, whereas C is moving in opposite direction. A chooses B as its next hop neighbor even though C is the closest next hop neighbor to D within A’s communication range, while mentioning direction first forwarding scheme. Those facts mentioned above motivate to take both information of position and direction into consideration when choosing the next hop neighbor. Weighted score (Wi) that mentioned in section IV (B) includes tradeoff between position-first and direction-first forwarding schemes. In PDGR, weighted score Wi is calculated for choosing the next hop neighbor.

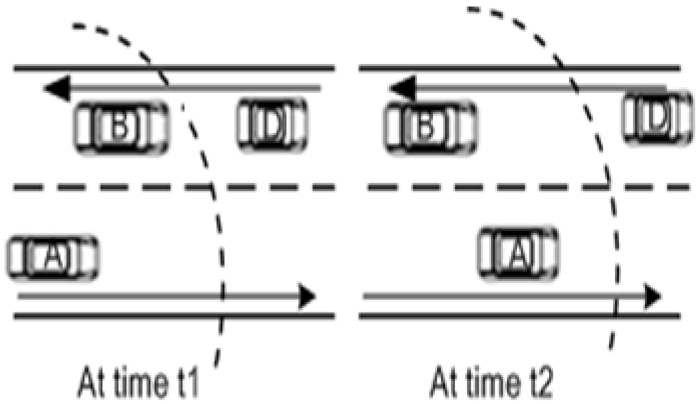

Figure 4-2: Routing loop in position-first forwarding

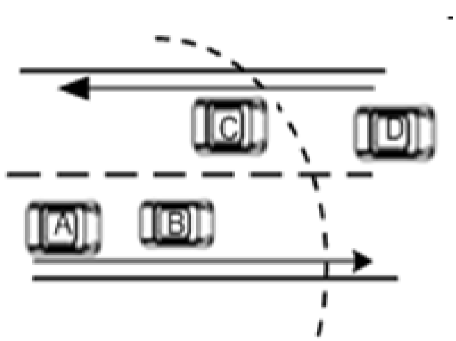

Figure 4-3: An unreliable neighbor selection in directional-first forwarding

C. Maintenance of Routing and Neighbor Table

Every node in the network periodically broadcasts routing information (RI) packet to its neighbors. The RI packet consists of the following fields: node_id, location_of_node, velocity_of_node, and direction_of_node. With the exchange of RI packet, each node maintains a neighbor table of its neighbors. When a node enters within a threshold T of a vertex j , the node adds information Vj in its RI packet. Upon receiving a RI packet containing Vj information a source node calculates $RT(i, j)$ of a node i within the threshold T of vertex j .

The routing table is constructed by exchanging only the RI packet of vehicles within threshold *T* of vertex *j*. This is why VPGR maintains routing table only for the involved vertices between the source vehicle and nearest fixed infrastructure or AP. It is noted that there is no need to maintain the routing table for all the involved nodes between the source vehicle and the fixed infrastructure or AP.

Table 4-1: Routing operation at the three kinds of nodes and at infrastructure or access point (AP)

Operations	Source vehicle	Intermediate vehicle	Vehicle within the threshold of a vertex	Infrastructure or Access Point (AP)
Vertex Selection	1. Identify presence of vertices between the nearest AP from it. 4. Upon receiving *RT (i, j)* predict a sequence of vertices and write it on packet header.	2. Maintain neighbor table 5. Up on receiving *RT (i, j)* of node *i*, forward it to a source node.	3. Calculate remaining time *RT(i, j)* of a node *i* within a threshold *T* of Vertex *j*. 6. Forwards) *RT (i, j)* of node *i* to intermediate node.	N/A
Predictive directional greedy routing	1. Maintain a neighbor table and calculate *Wi* for itself, current neighbors and 2-hop neighbors after that forward the packet to its neighbor with highest *Wi* otherwise carry it.	2. Upon receiving data from source node repeat step 1.	3. Upon receiving data from intermediate node repeat step 1.	4. Receive data from intermediate vehicle or vehicle within the threshold of the vertex.

V. Performance Evaluation

In this section, we evaluate the performance of our proposed routing protocol using the NS-2 simulator [22]. We compare the performance of VPGR with existing routing protocols of AODV [23] and GPSR [8]. AODV and GPSR are the representative reactive and geographic routing protocols, respectively, for VANETs.

A. Mobility Model

The mobility model used in the simulation has a great impact on protocols behavior and the obtained simulation results. For this purpose we used the Manhattan mobility model [24] to our needs and routing context. Manhattan mobility model emulates the movement pattern of mobile nodes on streets defined by city maps. This model is useful in modeling movement in city environments. The scenario is composed of a number of horizontal and vertical streets. At an intersection of a horizontal and a vertical street, the mobile node can turn left, right or go straight with certain probability.

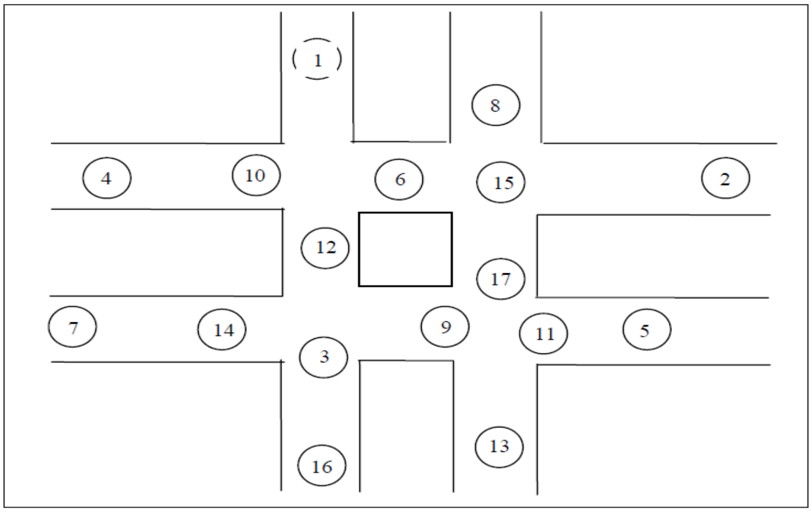

Figure 5-1: Topography showing the movement of nodes for Manhattan mobility model [24]

B. Simulation Setup

The experiment is based on a 1000m×1000m rectangle street area, which presents a grid layout. For the simulation, 1000m×1000m area is chosen, which consists of 9 junctions or intersections and 6 two way roads. This street layout is derived and normalized into a realistic mobility traces from a Manhattan mobility model [24]. These map data are transformed into the data format that can be used by ns2, simulator tool.

Different numbers of vehicles are deployed on the map. Each vehicle has radio propagation range of 250 m. The speed of vehicle is chosen. For the performance evaluation 6 random connections were established using CBR traffic varying 1-16 packet(s)/second with a packet size of 128 bytes. IEEE

802.11 is used for the network interface with channel capacity of 2Mbps. The simulation results are averaged over ten runs. Each simulation takes 900 seconds of simulation time.

Table 5-1: Simulation parameters

SIMULATION/SCENARIO		**MAC/ROUTING**	
Simulation area	1000×1000 m^2	MAC protocol	802.11 DCF
Simulation time	500 seconds	Channel capacity	2Mbps
Number of intersections	9	Communication range	250m
Number of two way roads	6	Traffic model	6CBR connections
Number of vehicles	100-500	Packet sending rate	(1-16) packets/sec
Vehicles' velocity	(20-80)km/hr	Data packet size	128
Mobility model	Manhattan mobility model [24]		

C. Simulation Results and Analysis

The performance metrics used to evaluate the simulation results are as following:

- *Packet delivery ratio:* The ratio of originated data packets that are successfully delivered to their destination vehicles to the original sent ones.

$$packet\_delivery\_ratio = \frac{number\_of\_received\_packets}{number\_of\_sent\_packets} \quad \ldots\ldots\ldots$$

- *Average end-to-end delay:* The average time it takes for a packet to traverse the network from its source to destination.

  Average end-to-end delay= average value of delivered packet's timestamp – generated packet's timestamps

- *Routing overhead:* The ratio of number of bytes of total control packets to those of total data packets delivered to the destinations during the entire simulation.

$$routing\_overhead = \frac{number\_of\_routing\_packets}{number\_of\_received\_data\_packets}$$

The routing protocols are compared under various data transmission rates, various vehicle densities and various maximum speeds of vehicles. For the traffic generation in variable node densities, we have taken the constant packet sending rate i.e., four packets/second. On the other hand for the traffic generation in variable speed, we have chosen constant number of nodes and packet sending rate i.e., 200 and 4 packets/ second respectively. Consequently, for the traffic generation in variable packet sending rate we have kept number of nodes constant i.e., 200 nodes. Detailed analysis of the simulation results are given in the following.

1. Packet Delivery Ratio

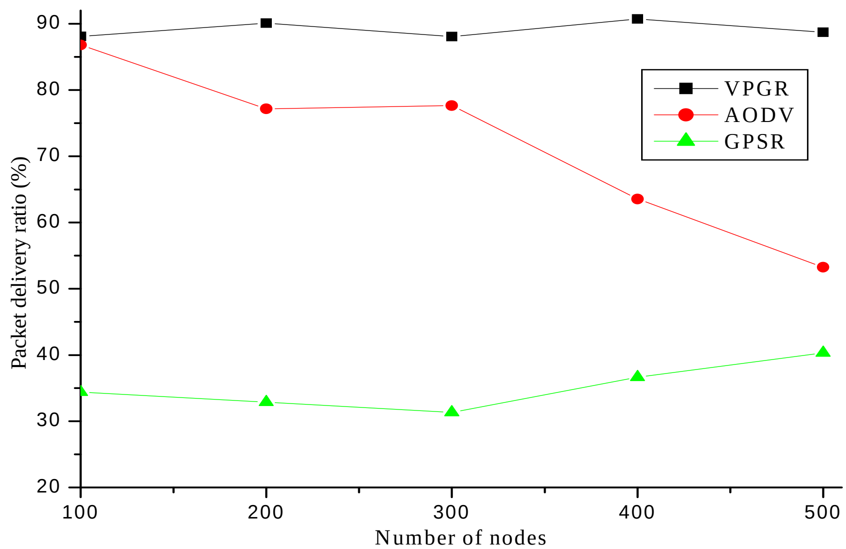

Figure 5-2: Packet delivery vs. number of nodes

In this part, we compare the performance of VPGR, AODV, and GPSR in terms of packet delivery. For the better performance, designed protocol should be tolerable to a small packet loss. We will show how the packet delivery is affected by the number of nodes, packet sending rate, and speed of nodes.

In Figure 5-2, in case of GPSR and VPGR it is observed that more packets are delivered as the number of nodes increases. This is expected since more nodes increases the probability of connectivity, which in turn reduces the number of packets dropped due to local maximum. But, it is also observed that GPSR did not show a better performance than AODV, possibly because perimeter mode does not pose fewer problems in delivery than in AODV. With prediction technique, VPGR shows the best performance because it can select best vertex to route the data and best next hop which enhance in packet delivery. As much as 50% more packets are delivered by VPGR than GPSR.

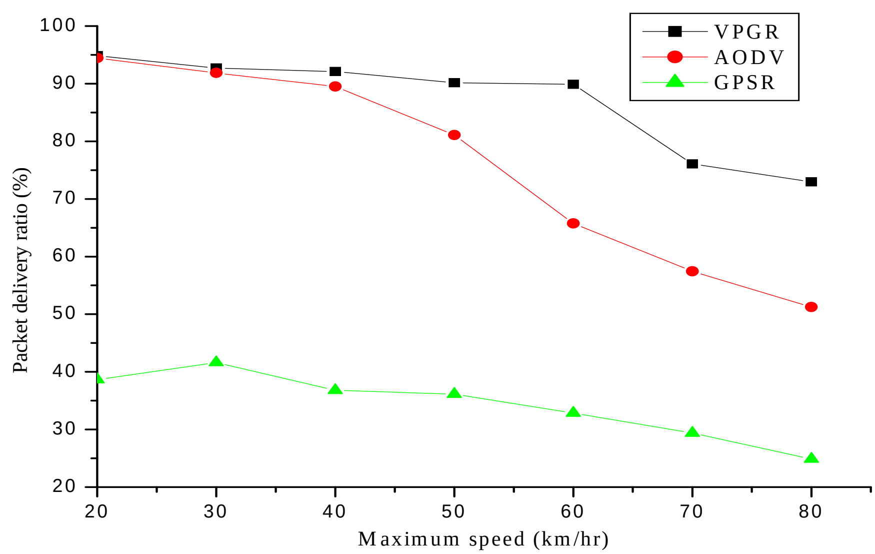

Figure 5-3: Packet delivery vs. maximum speed

Figure 5-3 shows the packet delivery ratio with respect to varying maximum speeds. The delivery ratio of GPSR is worst among three routing protocols (i.e., less than 40%). This is because GPSR suffers from frequent routing holes at the node placement only in perimeter mode. The delivery ratio of AODV is linearly decreases as the maximum speed increases. Since AODV is a reactive routing protocol, it performs route recovery whenever the packet drops due to route breakage. Whereas, VPGR performs higher delivery in all the speed level because in VPGR source node found the predefined route (i.e. always through predefined valid vertices) to the destination since it uses prediction technique to find next-hop neighbor. In case of VPGR, the packet delivery ratio is slightly decrease after maximum speed is 60km/hr; this is because with maximum speed remaining time of vehicles are short which results in a drop of packet. But still maintains almost 80% of packet delivery when maximum speed of node is 80km/hr.

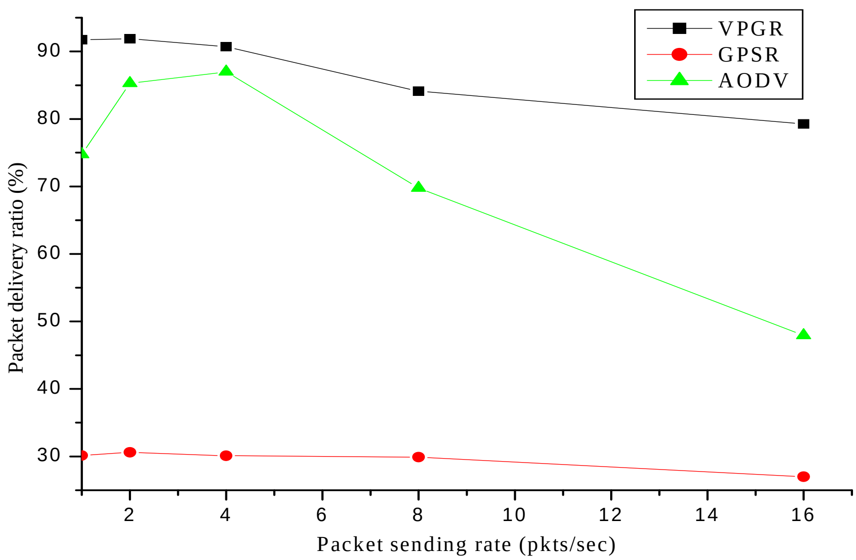

Figure 5-4: Packet delivery vs. packet sending rate

Figure 5-4 shows packet delivery ratio in varying packet sending rates. VPGR outperforms AODV and GPSR in packet delivery ratio for all the data rates. Whereas, GPSR has worst performance i.e. less than 30%; beyond sending rate 2 up to 16 packets. In case of AODV, delivery ratio increases up to almost 88%; but, when packet sending rate is beyond 4 the delivery ratio starts decrease steeply.

2. End-to-end Delay

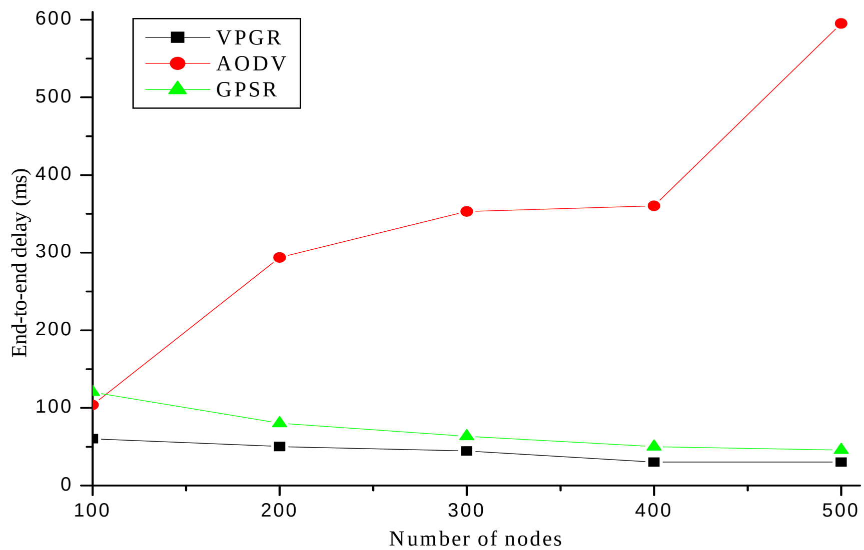

Figure: 5-5: End-to-end delay vs. number of nodes

In this section, we compare the performance of VPGR with GPSR and AODV terms of end-to-end delay. As shown in the figure 5-5, VPGR achieve a much lower end-to-end delay than GPSR and AODV in all the configurations. This is because, in VPGR, the number of hops involved to deliver packet is reduced due to predictive directional greedy routing (PDGR) is used to forward packets between source and fixed infrastructure or AP and also because VPGR does not need to keep track of an end-to-end route before sending packets from source to AP. In contrast, the reactive routing protocol like AODV uses a route discovery mechanism which causes longer delay. We can see while number of node reaches up to 150 end-to-end delay is increased unexpectedly. On the other hand, in GPSR when source node encounter situation of local maximum; source node forwards the packet in perimeter mode which results in a longer delay. Consequently, with increasing number of nodes chances of local maximum is low that is why, end-to-end delay decreases slightly even in the increasing nodes' number.

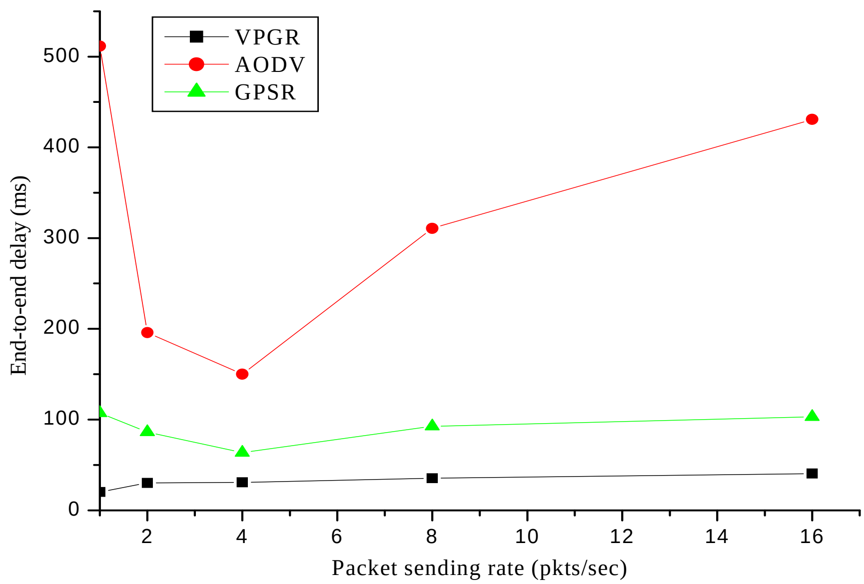

Figure: 5-6: End-to-end delay vs. packet sending rate

In figure 5.6, we evaluate the end-to-end delay to route the packet from source to destination in varying packet sending rates. VPGR has lowest end-to-end delay with compare to AODV and GPSR. In AODV, while sending rate is 2 packets/sec end-to-end delay increased linearly. This is because AODV needs the route acquire process (RREQ flooding, RREP unicasting) whenever the current path is broken. This results in a larger delay in AODV. In GPSR, we can't see such a larger fluctuations; up to packet sending rate 8 delay is slightly decreases but, after that point its starts slightly increasing. Even though, end-to-end delay in GPSR is higher than VPGR in every configurations because, it transfers packet in a perimeter mode and takes longer time to route the packet.

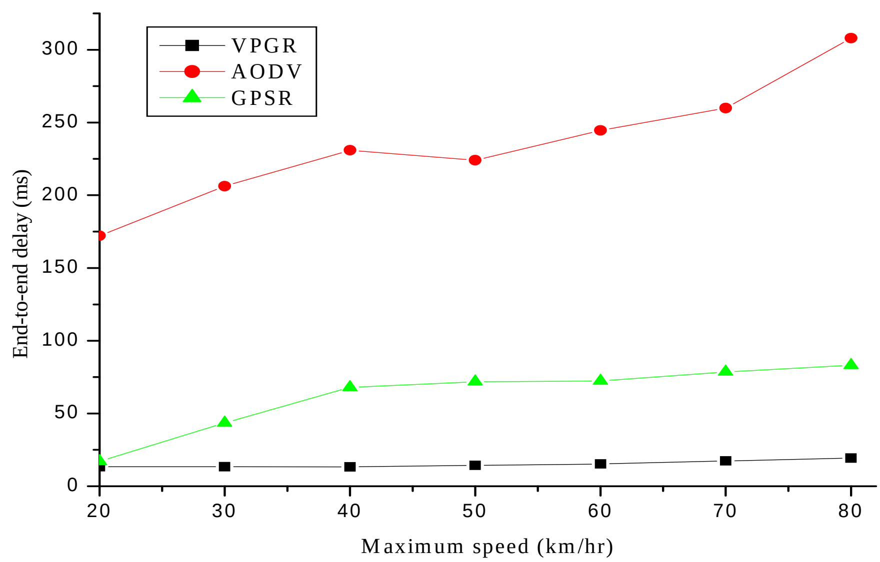

Figure: 5-7: End-to-end delay vs. maximum speed

As shown in figure 5-7, the average delay of VPGR has much more lower end-to-end delay among three routing protocols. AODV performs a route discovery process in reactive way whenever the current path or route is broken. That is why AODV to be worst in terms of end-to-end delay and linearly increasing with increasing maximum speed. As speed of node increases, it results in a link breakage. Consequently, GPSR also encounter longer delay than VPGR. Since packets are transmitted in perimeter mode which takes multiple hops and experiences longer delay as well.

3. Routing Overhead

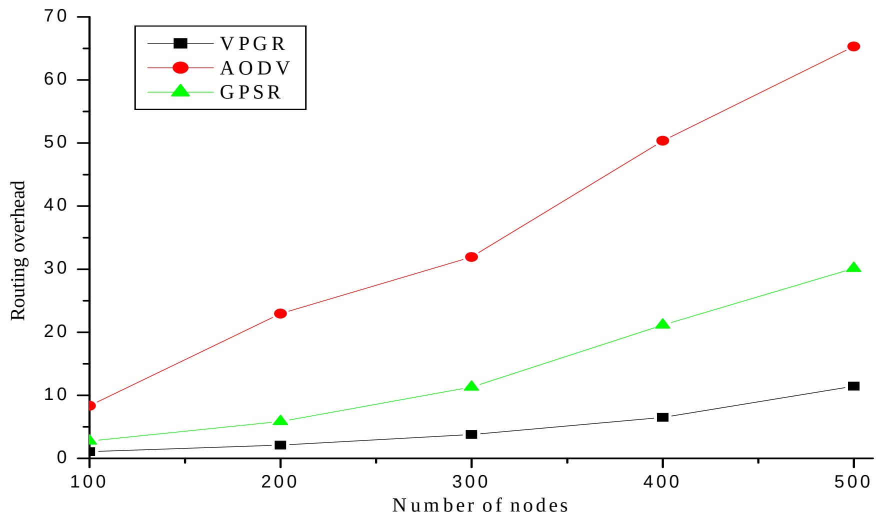

Figure 5-8: Routing overhead vs. number of nodes

In figure 5-8, we evaluate the routing overhead of the three routing protocols with different node densities. We observed that the increase in vehicle density leads on the increase in routing overhead since the rate of control messages depends on the number of nodes. In general VPGR outperforms other two routing protocols in all the configurations. This is expected in VPGR, we have only the RIA packet as a control messages. Whereas in AODV, we have three types of control messages (RREQ, RREP AND RERR) used for route discovery and route maintenance process. GPSR uses HELLO packet and VPGR uses only routing information (RI) packet as a control message.

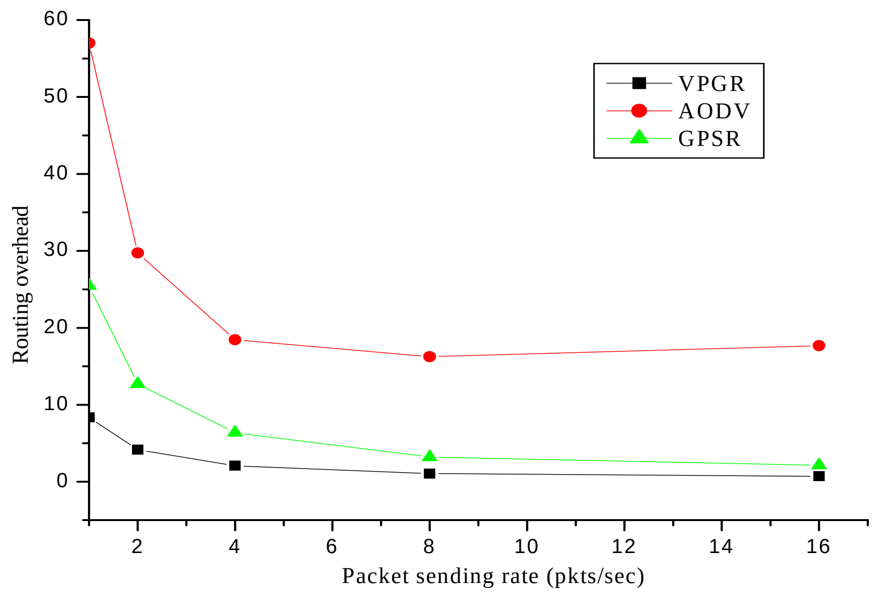

Figure 5-9: Routing overhead vs. packet sending rate

In figure 5-9, we evaluate the routing overhead of three routing protocols as a function of data sending rate. It is observed that, routing overhead decreases for all the protocols with increasing in packet sending rate up to 4 packets/ sec. But, beyond 4 packets/ sec routing overhead remain almost constant in all of the routing protocols. This is expected since the number of control messages is constant for same number of nodes (i.e. number of nodes is set to 200).

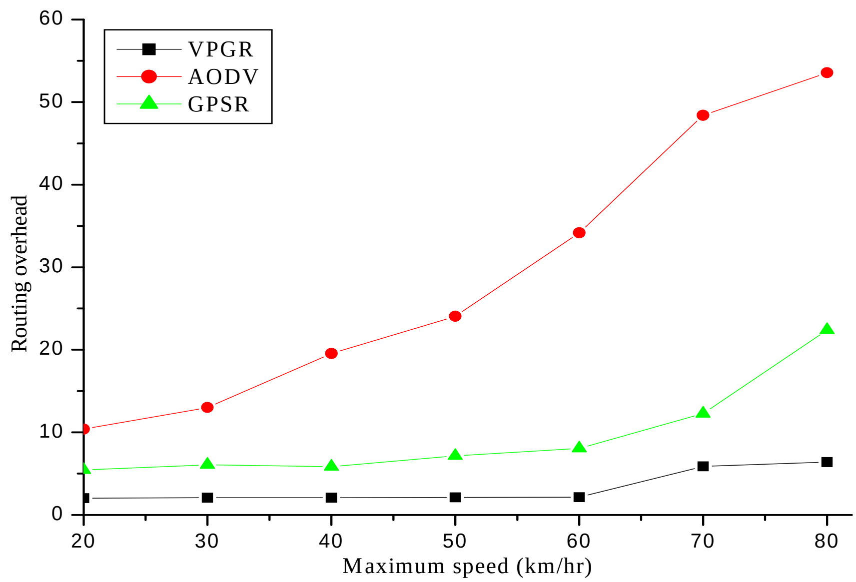

Figure 5-10: Routing overhead vs. maximum speed

In figure 5-10, we evaluate the routing overhead of the three routing protocols with varying maximum speeds. We observed that the increase in vehicles' speed increase in routing overhead since the rate of control messages depends on the number of nodes. In general, VPGR outperforms other two routing protocols in all the configurations. This is expected in VPGR, we have only the RIA packet as a control messages. Whereas in AODV, we have three types of control messages (RREQ, RREP AND RERR) used for route discovery and route maintenance process with increasing speed of node that is why it is increases linearly. GPSR uses HELLO packet and VPGR uses only routing information (RI) packet as a control message. We can see up to maximum speed is 60km/hr, in VPGR and GPSR have no changes in routing overhead but, beyond speed is 60km/hr routing overhead of VPGR is slightly increases.

VI. Conclusion

In this research the geographic prediction based routing protocol so-called vertex based predictive greedy routing (VPGR) protocol has been proposed for vehicular ad hoc networks in city environment. VPGR leverages the geographic position, velocity, direction and acceleration of vehicles and performs the two key operations of (i) the prediction of a sequence of vertices and (ii) the use of the predictive directional greedy routing to forward the data from source vehicle to destination through the sequence of vertices.

The proposed routing protocol has been evaluated using the network simulator ns-2 (version 2.33) and compared with GPSR and AODV for different conditions. The simulation results show that VPGR outperforms GPSR and AODV in terms of packet delivery ratio, routing overhead and end-to-end delay. That is, VPGR achieves higher performance and more reliable routing than GPSR and AODV.

Our proposed protocol selects vertices and intermediate vehicles in the city environment where sufficient vehicles are on the roads. As a future work, we are investigating the scenarios with variable vehicle densities to extend VPGR.

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논문제목	한글 : **차량 애드혹 네트워크를 위한 정점 기반 예측 그리디 라우팅 프로토콜** 영어 : **A Vertex Based Predictive Greedy Routing (VPGR) Protocol for Vehicular Ad Hoc Networks**				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

\- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의(○) 반대( )

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