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Context-Aware Two-Level QoS Routing in Vehicular Ad-Hoc Networks

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Dedicated to

My Parents and Teachers

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Abbreviations

VANET	Vehicular Ad-hoc Network
MANET	Mobile Ad-hoc Network
QoS	Quality of Service
CTQR	Context-aware Two-level QoS Routing
ITS	Intelligent Transport System
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
AODV	Ad-hoc On-demand Distance Vector routing
DSR	Dynamic Source Routing
ZHLS	Zone-based Hierarchical Link State routing
OLSR	Optimized Link State Routing
GR	Geographic Routing
GV	Gateway Vehicles
LSP	Link State Packet
RREQ	Route Request
RREP	Route Reply
IDM	Intelligent Driver Model
MOBIL	Minimizing Overall Braking Induced by Lane change
CBR	Constant Bit Rate
GPSR	Greedy Perimeter Stateless Routing

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Abstract

Vehicular ad hoc networks have received considerable attention in recent years. Being a subclass of mobile ad hoc networks, VANETs have some different characteristics than MANETs such as, fast moving nodes and frequent disconnections in the network. Existing routing protocols of MANETs do not perform well under these dynamic conditions in VANETs. This thesis presents a two-level context-aware routing protocol based on road connectivity in VANETs with QoS guarantee called Context-aware Two-level QoS Routing (CTQR) designed specifically for inter-vehicle communication in urban and/or highway environments. A distinguished property of CTQR is its ability to not only discover the available paths between source and destination pairs, but also to re-adjust the paths on the fly, without starting a new destination discovery process. It can select the best available path based on QoS parameters that are calculated using the vehicle context such as, velocity. Unlike other routing protocols, the path from source to destination is made by road ids. Gateway nodes help in locating the destination, forwarding the packets from one road segment to other, and calculating the QoS parameters. For the evaluation of CTQR protocol, extensive simulations were performed and results show that CTQR can help in design and deployment of VANETs.

1 Introduction

1.1 Background

Vehicular Ad-hoc Network (VANET) is a subclass of Mobile Ad-Hoc Networks (MANETs) and in the recent years, it has become an important area of research because of its promising solutions to Intelligent Transportation System (ITS). VANETs are characterized by highly mobile nodes and are constrained by movement patterns. VANETs have a highly dynamic topology due to the fast moving vehicles. Vehicles with active connection can have link failure frequently because of the short lifetime of the connections and unpredictable drivers' behavior. Due to these characteristics of VANETs, it becomes a challenge to provide an efficient routing protocol that can deal with the dynamic characteristics of VANETs. Due to the dynamic characteristics of VANETs, e.g., frequent disconnections and fast moving nodes, it becomes a challenge to provide delay sensitive or bandwidth intensive applications. Therefore, any Quality of service (QoS) model provided for VANET should be able to tackle the variety of the aforementioned requirements. Thereby, QoS provisioning in VANETs pose a real challenge.

There are two types of communication in VANETs. As shown in Figure 1, V2V communication allows vehicles to communicate directly without the help of any other network element. V2V is some-times referred as ad-hoc communication. V2I (infrastructure-based) communication involves network infrastructure such as, RSU, SSU, and/or network servers. V2I is preferred for dense traffic scenarios [19].

Vehicles move along the roads so a road-aware approach is needed that can use the road information efficiently to reduce the bandwidth utilized by the routing packets. A road between intersections can be treated as a zone or a segment, and vehicles on a road segment usually have similar communication characteristics/conditions. If the routing information of each road is considered separately, the change in vehicle topology can be handled on the local road segments very efficiently without utilizing the bandwidth of the entire network.

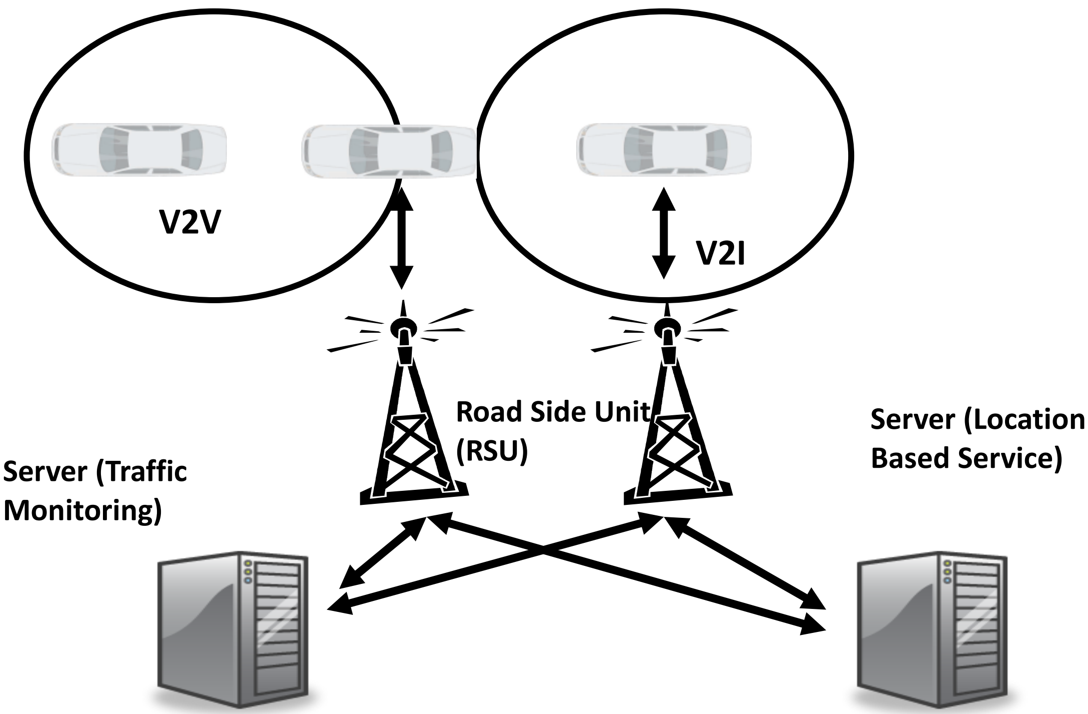

Figure 1: VANET communication types

In the past, different types of routing protocols are proposed. One type of routing protocols, such as, AODV [2] (Ad-hoc on Demand Distance Vector Routing) and DSR [3] (Dynamic Source Routing) do not maintain routing tables all the time. However, before starting the data transmission, source vehicle sends a route request to find available path to the destination. If the destination moves away from its location or the path between source and destination somehow breaks, the process of destination discovery has to be initialized from the start. While other type of protocols, e.g., OLSR [4] (Optimized Link State Routing) and ZHLS [5] (Zone-based Hierarchical Link State Routing) maintain routing tables and update them periodically. These routing protocols are expensive in terms of routing packets as they update the routing tables periodically. Therefore, reducing the control overhead in VANETs remains a challenge for researchers.

Figure 2 lists the routing classifications for VANETs [19]. These protocols are divided in two main categories: network topology based protocols and protocols that use additional information. Discussion about the protocols that use additional information is out of scope of this document. The work presented in this document is classified as network topology based routing protocol.

Proactive routing refers to the classical Internet routing protocols. Information about the topology is collected before any data is available to be transmitted over the network. The advantage is that information on adequate paths is available instantly whenever data is ready for transmission. The downside is that the routing protocols have to continuously update the topology, which is especially hard in dynamic environments such as vehicular networks, even if no transmissions are scheduled.

Reactive routing solutions prevent the continuous topology update if no data is to be transmitted. Thus, the network is trying to prevent maintenance if current topology information is simply not needed. Instead, topology management is started anew for each data packet to be transmitted.

Hybrid solutions try to combine the advantages of both worlds. The most direct approach is to follow a hierarchical concept, e.g., using reactive routing at the lower level in clusters of nodes but proactive routing among the different clusters.

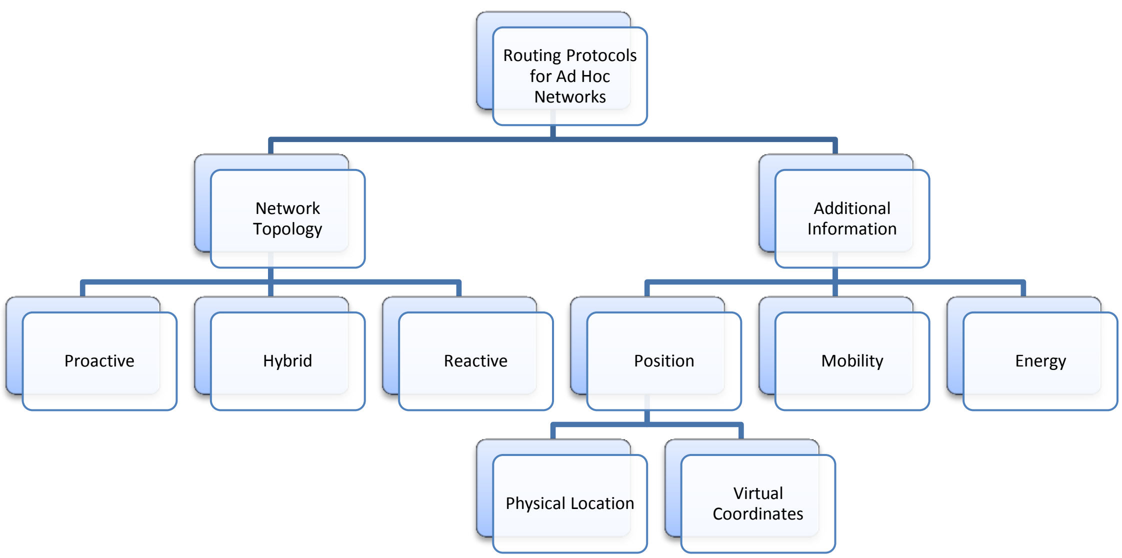

Figure 2: Routing Classifications for VANETs

In recent years, Geographic Routing (GR) is studied specially to deal with node mobility in VANETs. Position based routing does not require routing tables maintained in each node. It is considered scalable with respect to the size of the network and is therefore an excellent candidate for the vehicle communication. The geographic routing can select the forwarding nodes in a flexible manner by using location information of nodes. Several GR protocols are proposed specifically for VANETs, e.g., [7], [8], [9]. However, most of them use the global view of the simulator and location of destination is already known. Therefore, these protocols have zero location service overhead. Furthermore, the performance of GR protocols still needs to be improved in terms of delivery ratio and end-to-end delay for real-time and safety applications.

Many QoS routing protocols have been proposed. In [16], authors propose a QoS routing protocol to find the reliable routes to destination which is calculated on demand from a source i.e., a base station or vehicle. DeReQ [17] is another proposed QoS routing protocol for multimedia applications. In [18] authors discuss AQVA, a QoS routing protocol to provide reliable communication. None of these existing QoS routing protocols consider the localization approach i.e., selecting the route by combining links on each zone that fulfill the QoS requirements. I focus my interests on providing QoS constraints routing algorithm for VANETs as I believe this opening issue is a bottleneck problem for multimedia and/or time sensitive application in VANETs.

1.2 Context of research

This thesis presents a novel position-based hierarchical routing protocol based on road connectivity called Context-aware Two-level QoS Routing (CTQR) designed specifically for inter-vehicle communication in an urban and/or highway environment. It can find the most reliable path among all available paths. CTQR integrates locating destination with identifying available paths between source and destination. Gateway Vehicles (GV) help in connectivity between different road segments. Destination discovery process does not flood the network with the packet broadcasts. The link/path quality is determined by three parameters; link availability time, degree of link failure recovery and hop count for transmission over the path. Once a path is discovered, it is adjusted on the fly to account for changes in the topology, without initiating a new destination discovery request. The proposed protocol is two-level because it uses proactive routing on local roads and reactive routing for global routing to reduce the routing overhead.

1.3 Outline

This thesis document is organized as follows: Related work is discussed in Section 2. Section 3 discusses the Context-aware Two-level QoS Routing (CTQR) protocol. Simulation setup and the results of CTQR are given in Section 4. Section 5 concludes the thesis.

2 Literature Review

2.1 Routing

Connectivity Aware Routing (CAR) [1] is a position-based routing protocol designed for VANETs. It uses adaptive beaconing to create and maintain neighbor routing tables. CAR introduces the concept of "Guards" that help in path failure recovery process. Optimized broadcast is used to discover the location of the destination vehicle. However, the discovery packet is received be all vehicles between source and destination at-least for once. Greedy forwarding is used over the discovered path.

Road Topology-aware Routing (RTR) [10] extends the destination discovery mechanism of AODV [2] to discover two junction-disjoint routing paths. Source node uses one of the established paths rather than all paths for one packet forwarding so that communication overhead is reduced. When both two junction-disjoint paths are connected, they are chosen alternately to transfer data packets. RTR utilizes two junction-disjoint paths to transfer data packets, which avoids network congestion and link failure in a single routing path. However, the control overhead for discovering the destination is even more than that of AODV because the RREP is sent back to source by the destination over two different paths.

Zone-based Hierarchical Link State routing (ZHLS) [5] is a link state routing based protocol for MANETs which divides the network into zones and routes the traffic through the zones. Each node only knows the node connectivity within its zone and the zone connectivity of the whole network. The link state routing is performed on two levels: local node and global zone levels. Unlike other hierarchical protocols, there is no cluster head in ZHLS. The zone level topological information is distributed to all nodes. It provides a flexible, efficient, and effective approach to accommodate the changing topology in a wireless network environment. However, the distribution of zone level topological information to all nodes in the network introduces a huge amount of routing overhead.

There are some proposed GR protocols that return the shortest path between source and destination [8], [9], [11]. However, it is not always possible that the shortest path between source and destination is populated. Furthermore, if the local maximum is reached at any point, a new route is calculated. This process may take some time and may waste network capacity. Typically, GR protocols require the location information of the destination before starting the data forwarding process. The majority of proposed GR protocols assume destination location is known at any time [12], [13], [14]. The performance of these protocols is evaluated with zero location service overhead. However, it remains unclear how destination location discovery process can influence the network capacity. Moreover, if the destination vehicle moves a substantial distance from its known position, these protocols fail.

2.2 QoS

Most of the existing QoS routing protocols are designed for traditional MANETs. These protocols do not work under the dynamic characteristics of VANETS. Also, the QoS routing protocol for VANETs have not been introduced to that extent. GvGrid [16] is a stable QoS routing protocol to find the route between source and destination. It proposed two algorithms named as neighbor selection algorithm and the route selection algorithm for selecting a route by vehicles moving at similar speeds and directions. GVGrid constructs a route on demand from a source i.e. fixed node or a base station to vehicles that reside in or drive through a specified geographic region and maintains a high quality route. DeReQ [17] is a QoS routing protocol proposed for the multimedia communication in VANET. It considers the traffic density as well as the impact of link duration to find a route which is reliable and also compliant with delay requirements. AQVA [18] is another proposed protocol that can provide the reliable communication for different type of services in VANETs. Most of the existing protocols are suitable for V2I (Vehicle to Infrastructure) mode of vehicle communication network, but in V2V (Vehicle to Vehicle) mode these protocols may reduce the network performance [20]. Communication links are established with frequent disconnects, increasing the packet loss rate and delay because of fast moving nodes, dynamically changing topology and complex environments [28].

In [26], the authors proposed a reliable routing protocol based on ad-hoc on demand distance vector (RQ-AODV) for VANETs. RQ-AODV finds a reliable route with multiple QoS constraints such as, bandwidth and delay. In [27], a new scheme is proposed to avoid packet collisions and reduce the number of rebroadcasts. Node does not rebroadcast packet immediately when it is received, but has to wait some waiting time to make a decision about whether it should rebroadcast or not. If node does not receive the same packet during this time, the packet should be rebroadcasted; if not, the packet should not be rebroadcasted. The waiting time depends on the distance of this node to the sender. The waiting time is longer for less distant receiver. But this scheme does not take into account the QoS constraints.

2.3 Gateway nodes

The concept of "Gateway Nodes" is not completely new. In [5], authors make use of gateway nodes in order to maintain connectivity between zones. There may be more than one gateway nodes between two zones: Therefore, it avoids single point of failure. A similar concept is used in UGAD [6], where vehicles at intersections are given the highest priority in order to avoid the transmission blocking by the buildings. Vehicles on the intersections can send/receive packets to/from other connected roads. Using these vehicles in an efficient manner can improve the performance of the routing protocol.

3 Context-Aware Two-Level Routing

This chapter presents multi-level position-based routing protocol called Context-aware Two-level QoS Routing (CTQR) designed specifically for inter-vehicle communication with QoS guarantee. In the first level of hierarchical model, vehicles generate link state packets (LSPs) containing their neighbor information to make road segment routing table. This proactive mechanism is only used for the routing on road segments between intersections. Vehicles use a context-aware adaptive approach to update the routing tables. In the second layer of hierarchical routing, source vehicle uses enhanced reactive routing mechanism to discover the path to destination. The path request is not sent to every vehicle rather it is only forwarded to a few vehicles on each road segment. Once a path is discovered, it is adjusted on the fly to account for changes in the topology without initiating a new destination discovery request. For each path from source to destination, a weight is calculated to evaluate the quality of path. Multiple parameters are considered to calculate the path quality weights. Unlike other reactive routing protocols, destination discovery process does not flood the network with the packet broadcasts.

Figure 3 illustrates the main modules of the proposed framework. The routing module consists of the two layer hierarchical routing that includes proactive and reactive at the same time. The decision module uses the context-aware approach to reduce the routing overhead. QoS provision block is responsible for the path weight calculation and quality of paths.

Description of information management module and applications block is out of scope of this document.

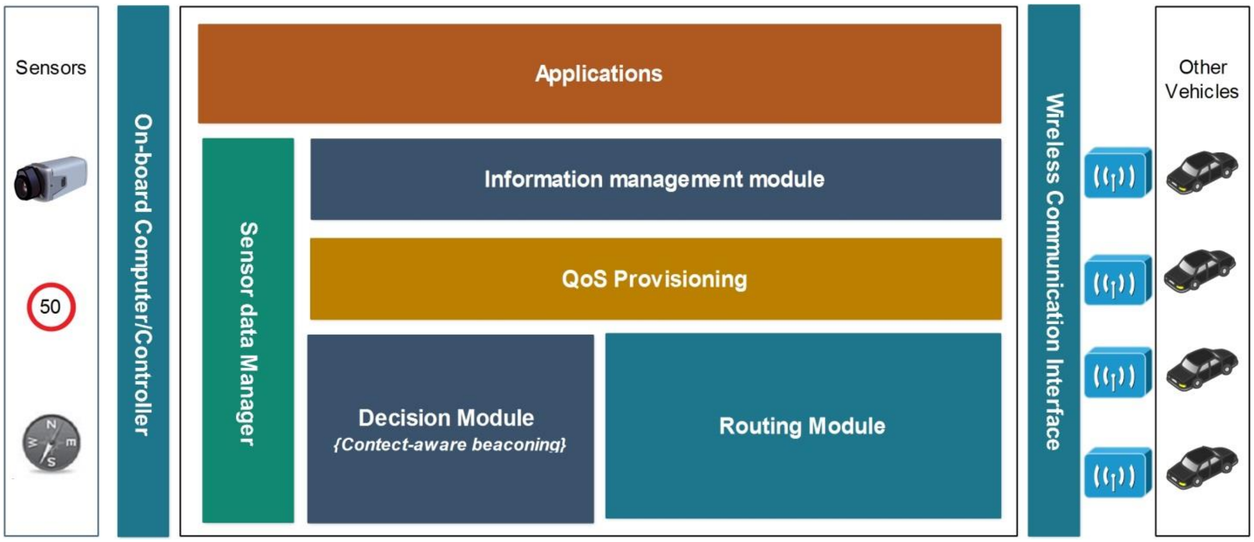

Figure 3: Framework

The CTQR protocol consists of five main parts: (1) road LSP generation; (2) context-aware beaconing; (3) path discovery; (4) packet forwarding over discovered path; and (5) path maintenance. The following sections explain the main modules of the presented protocol.

3.1 Neighbor Tables

In CTQR roads are divided into segments with unique roadIDs. Vehicles asynchronously broadcast link requests to discover their neighbors. Neighbors within communication range in turn reply to link request that includes <vehicleID, roadID, Position, Speed, Direction>. Vehicles wait for an interval to receive the response of link requests from their neighbors. After receiving the response of link requests from the neighbors, every vehicle generates its neighbor link state packet (LSP) which contains the information about all the neighbors of the vehicle. Vehicles then propagate their neighbor-LSP locally within their road segment via intermediate neighbors. Using the neighbor-LSP, a road-LSP for road 1 in Figure 4 is generated by every vehicle as shown in Table I. Vehicles may also receive neighbor-LSP from other roads. After receiving the neighbor-LSP from other vehicles, each vehicle knows the road segment level topology.

The vehicles on the intersection or near to intersections also receive link requests from the vehicles on different road segments. These vehicles are called the Gateway Vehicles (GVs). As shown in Figure 4 (with red color), vehicles S, E, G and H are gateway vehicles on an intersection. GVs provide connectivity between road segments. GVs use the information in neighbor-LSP's to make a road segment routing table as shown in Table II for vehicle 'S' in Figure 4. Since there may exist more than one path between intersections, GVs add all the paths to the tables. GVs propagate their routing table within the road segment to all vehicles.

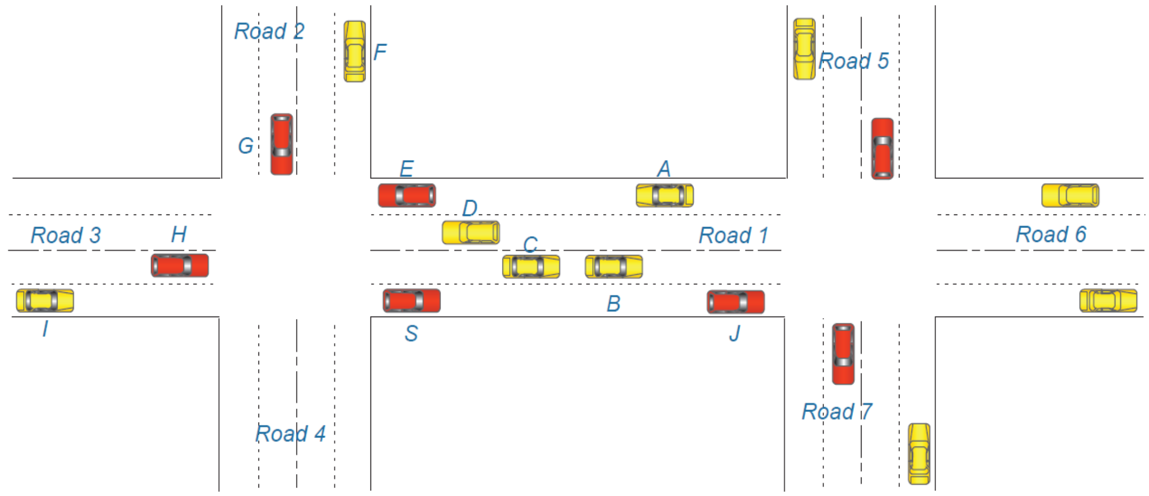

Figure 4: A simple intersection with gateway vehicles

Table I: Neighbor-LSP for road 1

Source	Neighbors
A	B
B	A, C, D
C	B, D, S
D	B, C, E, S
E	S, D, 2
S	C, D, E, 2, 3

Table II: Road segment routing table of vehicle S

Destination node	Next node
A	C, D
B	C, D
C	C
D	D
E	E
J	C, D
2	G
3	H

Usually in proactive routing protocol e.g. ZHLS [5], the process of link request is performed after a pre-defined time interval by every vehicle to detect the changes in the road topology and update the routing tables accordingly. If there is a change in the road topology, the protocol broadcasts entire LSP to keep the routing tables up-to-date. In the dense traffic scenarios where cars move with different velocities, the road topology keeps on changing. However, in some scenarios e.g., highway, most vehicles move with similar velocities and road topology does not change frequently. In such scenarios, the process of link request with a constant periodic interval causes routing overhead which can be decreased further with the use of predictive time interval for link request.

In this thesis, an enhanced context-aware beaconing mechanism is presented to decrease the routing overhead and improve the performance of the protocol. The aforementioned issue of routing overhead can be addressed by adjusting the time duration for transmission of LSPs among vehicles within the road segment. Time interval can be set by taking the dynamic nature of the vehicular network into account. Vehicles might not need to broadcast LSPs frequently when waiting at a traffic signal or when moving in a group on the same route. Moreover, when vehicles are moving with slow speed, the time interval for LSP broadcast can be increased and vice-versa, because when vehicles move with slow speed, the topology does not change as frequently as it changes when vehicles move with high speed. Therefore, considering all these properties of a vehicular network, an optimized context-aware mechanism is presented that enables vehicles to gather the neighbor information and local routing table while keeping a low routing overhead.

3.1.1 Context Aware Beaconing

Context represents the surrounding environment of the object which is under discussion, sometimes it is also used to represent the circumstances in which a task is carried out [21]. Context also represents the environment around the vehicle that directly/indirectly affects the different parameters. Context of vehicle can include speed, direction, location, number of neighbors, road condition, passengers inside the vehicle and/or the other surrounding attributes.

The context in our system is determined by the speed of vehicles and number of neighbor vehicles. The reason for choosing only these two parameters is that the proposed routing protocol only utilizes context when it needs to decide about the time interval of LSP broadcast. In this case, only speed and number of neighbors can be useful in determining the respective context of vehicles.

The context of a vehicle is calculated based on two aspects i.e., neighbor vehicle changing frequency and vehicular nodes speed on a road segment. To compute the ratio of changing neighbor nodes between two time stamps t_m and t_n where $t_n > t_m$ and $t_n = t_m + \Delta t$, a vehicle monitors the number of neighbors, number of neighbors that moved out of its range in time Δt, and number of vehicles that remained connected during Δt. Equation 1 presents the mathematical formula to compute the neighborhood stability of a vehicle.

$$Stb_N(t_n) = \frac{N_{new}(t_m, t_n) + N_{moved}(t_m, t_n)}{N_{connected}(t_m, t_n)} \qquad (1)$$

where $Stb_N(t_n)$ represents the ratio of change for vehicles in neighborhood of a vehicle from time t_m to t_n; t_n is the current time, t_m is the previous time stamp for LSP broadcast; $N_{new}(t_m, t_n)$ represents the new neighbors of a vehicle; $N_{moved}(t_m, t_n)$ are the vehicles that moved away from communication range within the time t_m to t_n; $N_{connected}(t_m, t_n)$ represents the vehicles that remain connected during time Δt, where $\Delta t = t_n - t_m$. The value of Δt is adaptive with respect to the speed and number of neighbors and is updated according to new time interval after each timespan.

When the neighbors of a vehicle change frequently, it represents the traffic mobility scenario in two dimensions; either the vehicle itself is moving with very high speed or the neighbors of the vehicle are moving with high speed. Equation 2 represents the formula to calculate speed stability of a vehicle.

$$Stb_s(t_n) = \frac{|v_c(t_n)|}{Avg(|v_i(t_n)|)} \qquad (2)$$

and

$$Avg(|v_i(t_n)|) = \frac{\sum_{i=1}^{n}(|v_i(t_n)|)}{n} \qquad (3)$$

where v_c presents the velocity of the current vehicle; n is the number of neighbors of the current vehicle. Equation 4 represents the traffic mobility using the stability values presented earlier.

$$Mob(t_n) = Stb_N(t_n) \text{ x } Stb_s(t_n) \qquad (4)$$

$$Mob_{dif}(t_n) = \frac{Mob(t_n) - Mob_{Avg}}{Mob_{Avg}} \qquad (5)$$

Till here, mathematical expressions to calculate stability and mobility for a vehicle are presented. Now the expression to compute the time interval for next LSP broadcast is described using mobility from equation 4. Equation 6 presents the formal mathematical formula for the time interval from current time i.e., t_n to the next time stamp i.e., $t_n + \Delta t$.

$$T_{int}(t_n, t_n + \Delta t) = T_{int}(t_n - \Delta t, t_n) - \left(\alpha \text{ x } Mob_{diff}(t_n)\right) \qquad (6)$$

where α is the tuning parameter and its optimal values are given in the results section. The next time interval for LSP broadcast is computed by the above equation and this process is repeated again when the next time span is reached. The following section describes the weight calculation model that is used to check the quality of each path from source to destination. The calculated weight determines the quality and provides QoS.

3.1.2 Path weight calculation

To provide reliable links, three different parameters are calculated for each link/path and the best one depending on the application requirements is selected. Since there may be multiple paths available between two intersections as shown in Figure 5, link reliability for each link is calculated locally on its road segment by the gateway vehicles to select the best route according to the application requirement. Every vehicle knows its neighbor's position and velocity from the beacons described in previous section. This information is used to calculate the time duration two neighbors will be in the communication range of each other. Equation 7 is used to calculate the time of link availability. The value of link availability time for a route is determined by the minimum link availability time value among all links in a route.

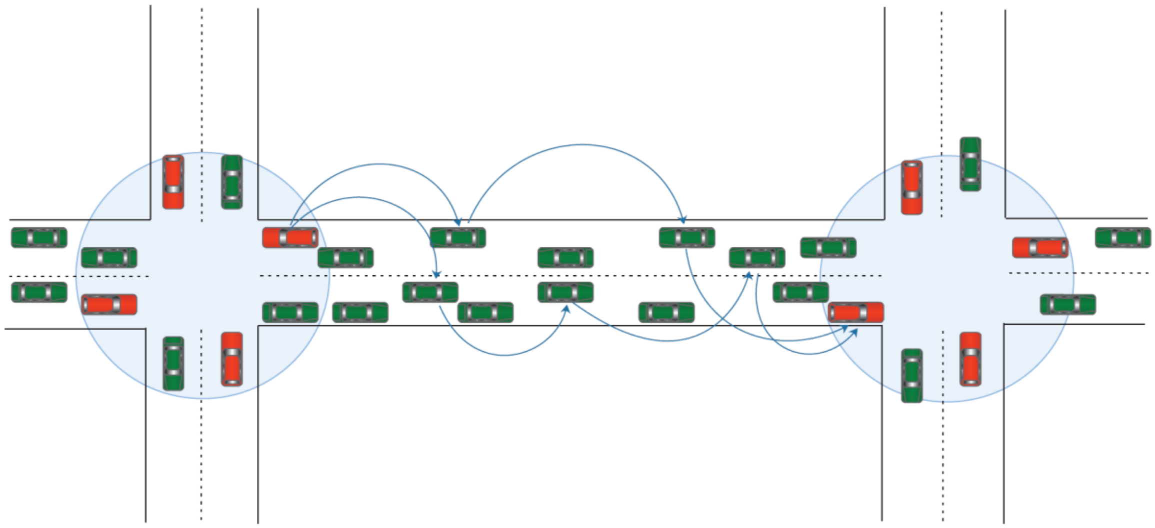

Figure 5: Multiple paths between intersections

$$LAT_{ij} = \frac{R - D}{|v_i - v_j|} \qquad (7)$$

where *R* is the communication range between vehicle *i* and *j*; *D* is the distance between vehicle *i* and *j*; *v* is the velocity of vehicles. If the cars have same direction, the denominator gives a less value increasing the link availability time. Whereas, if the vehicles are traveling in opposite direction, the velocities add up and the resulting link availability time is decreased. Due to high node mobility and channel limitations, there may be link failure between any two nodes at any given time. CTQR calculates the average neighbor vehicles degree for each link to calculate the degree of how fast a vehicle can find a new neighbor to reestablish the link. Equation 8 is used to find the average neighbors degree of a route.

$$Nd_r = \frac{1}{H} \cdot \frac{\sum_{i=1}^{H} N_i}{N_{i\_max}} \qquad (8)$$

where H is the hop count in the route; N_i is the number of neighbors in communication range of node i; N_{i_max} is the maximum number of neighbors of any node in the route.

The proposed protocol aims to minimize the delay in packet delivery between the source and destination. Hop count is an important parameter to consider for dealing with delay constraints. The proposed protocol considers the total hop count from source to destination to find the minimum delay route. The weight of link quality is calculated by equation 9. The weight of link quality W_i is larger, the route is more reliable.

$$W_i = \alpha \frac{LAT_i}{LAT_{max}} + \beta \frac{Nd_i}{Nd_{max}} + \gamma \frac{1}{Hx_i} \qquad (9)$$

where, W_i is the weight of link quality of the ith route; LAT_i is the value of link availability time of ith available route; LAT_{max} is the maximum value of link availability time among all available routes; Nd_i is the neighbor vehicle degree for the *i*th available route while Nd_{max} is the maximum neighbor vehicle degree among all available routes; Hx_i is the transmission count for the *i*th route; $\alpha + \beta + \gamma = 1$.

Every GV maintains a path weight table similar to Table III for vehicle *J* in the Figure 4. W_i is the weight of the path between intersections that can be selected by GV according to the requirement of the application.

Table III: Path weight table of vehicle J

Destination GV	Next node	Weight
S	A	W_1
S	B	W_2
E	A	W_3
E	B	W_4

3.2 Path Discovery

In level two routing, CTQR takes reactive routing approach. In order to find a path to a destination, CTQR uses route request/reply RREQ/RREP. Before sending the RREQ, source vehicle checks its road segment routing table to find the destination vehicle if it is on the same road segment. If the destination vehicle is on a different road than the source, the source vehicle sends a route request to the gateway vehicle. The gateway vehicle then forwards that RREQ to the gateway vehicles on all the connected roads. On the intermediate roads, the RREQ is forwarded using the road segment routing table from one GV to others. The gateway vehicles that receive the RREQ check their road segment routing tables to find the destination vehicle. Figure 6 shows the process of RREQ. The gateway vehicle that finds the destination vehicle on its road, replies the RREQ with route reply (RREP) packet. RREP is sent back as unicast to the source vehicle as shown in Figure 8. The process of RREP is illustrated by the graph in Figure 8 where intersections are the vertices and the roads are represented as edges. The root node is the first intersection near the source vehicle. The packet travels from one intersection to other towards the source. A flowchart explaining the path discovery process is shown in Figure 7.

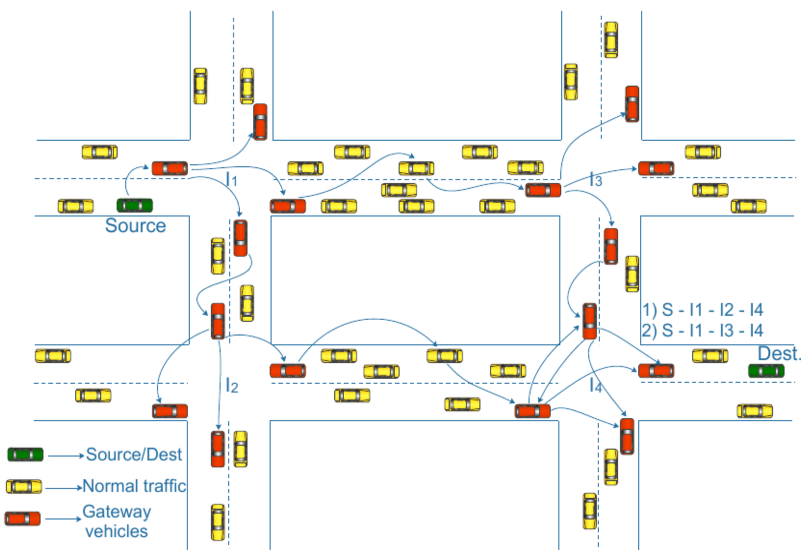

Figure 6: RREQ

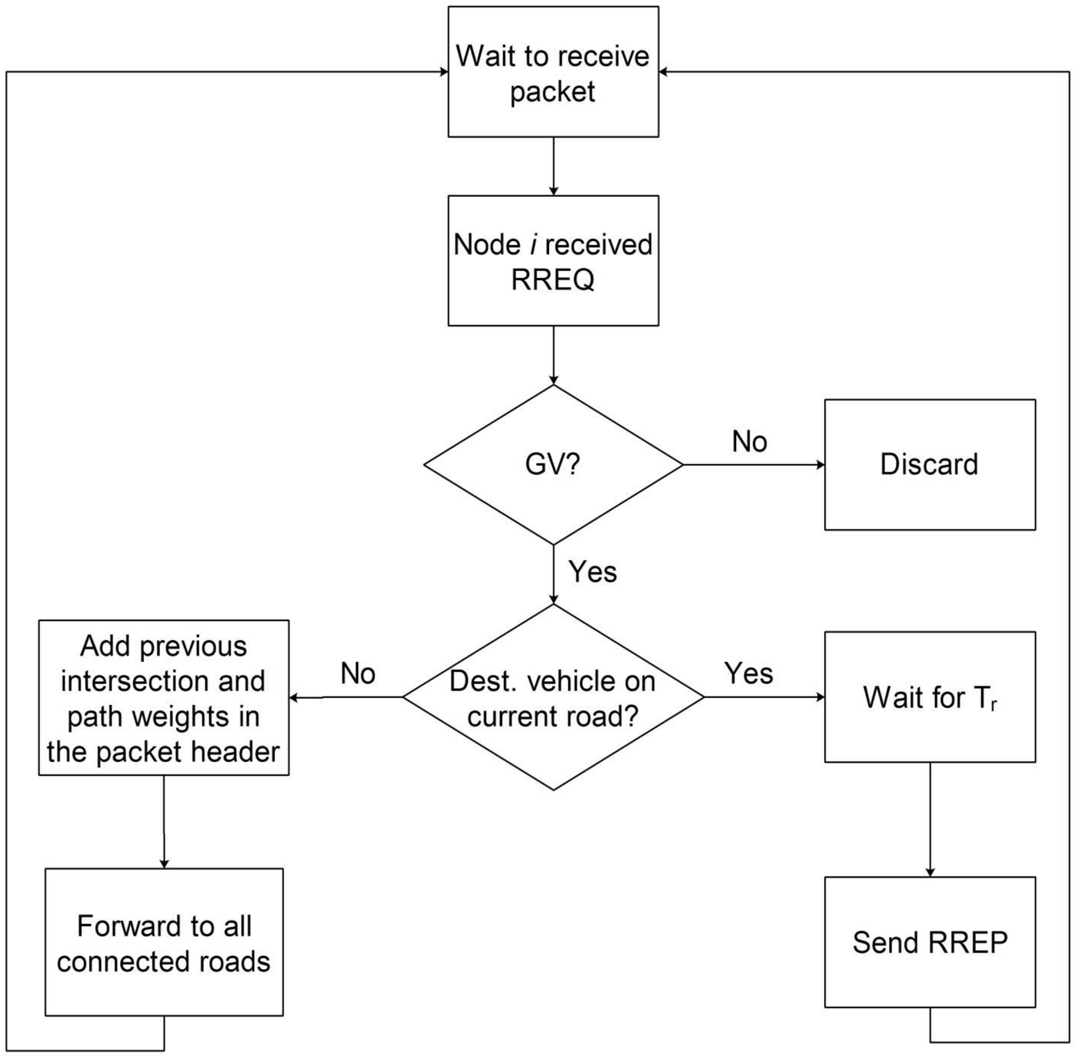

Figure 7: RREQ processing flowchart

In all the routing protocols that use RREQ/RREP, path in the RREP includes the vehicleIDs. However, CTQR uses roadIDs instead of the vehicleIDs. Reason for using the roadIDs in a path instead of vehicleIDs is because a link between two vehicles in the path may fail at any time resulting in decreased performance. Therefore, even after the link failure between any two intermediate vehicles, the packets can still be forwarded by other vehicles using their road segment routing table. The gateway vehicle that sends the RREP to the source, can receive more than one RREQ from different roads. However, only the shortest path in terms of distance and number of intermediate hops is selected by the gateway vehicle.

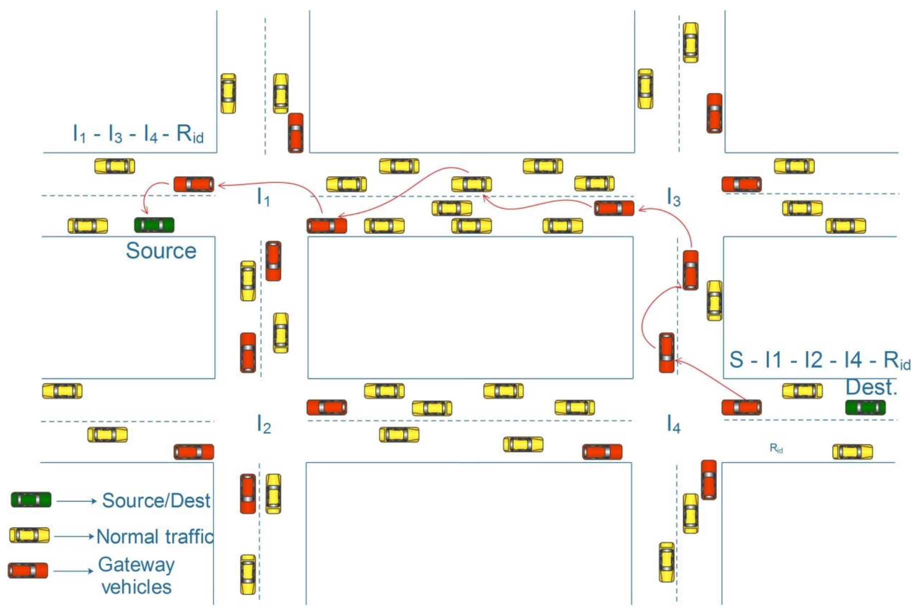

Figure 8: RREP

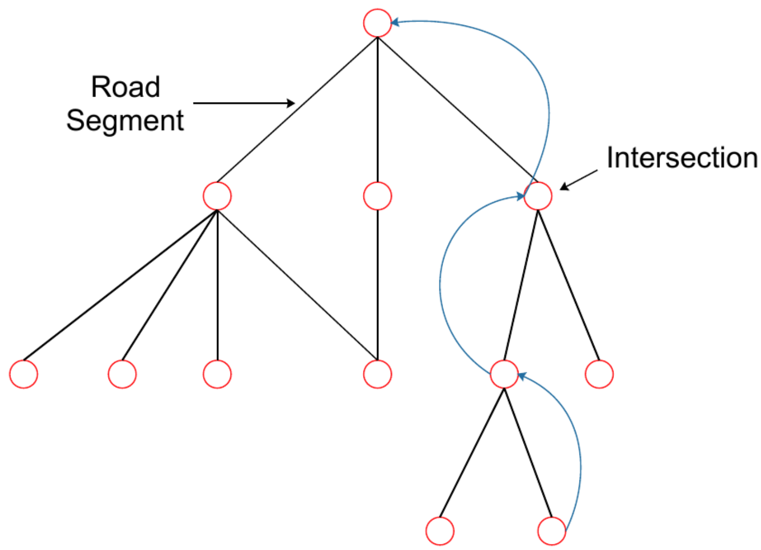

Figure 9: Graph representation of roads

3.3 Packet Forwarding over Discovered Path

The CTQR protocol uses road segment routing table to forward the packets towards the destination. The packets are sent from one intersection to another by the gateway vehicles. Intermediate vehicles use their road segment routing tables to route the packet towards next gateway vehicle. Since beaconing is a basic building block of all inter-vehicle communication protocols, CTQR extends its concept to generate the road segment routing tables. An illustration of intermediate vehicle packet forwarding can be seen in Figure 6.

3.4 Path Maintenance

Any path between source and destination may become invalid. Let us assume that the path between two intersections stays connected. Therefore, only possibility for a path to break is when end point vehicles (source and/or destination) move a substantial distance from the initial position. In such scenarios, majority of the previously proposed protocols fail because they have to start a new destination discovery process each time a path fails. The following section presents how gateway vehicles help to adapt to such situation without losing data packets and avoid starting a new destination discovery process. An illustration of path maintenance by the GV can be seen in Figure 10.

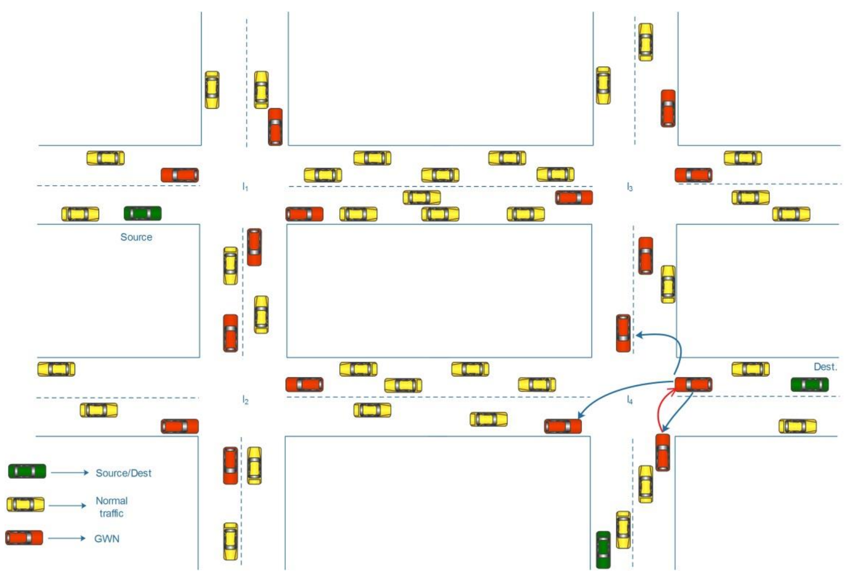

Figure 10: Path maintenance by GV

3.4.1 Gateway vehicles in path maintenance

When there is a data transmission going on, the gateway vehicles on both sides (source and destination) maintain a table of active connections. The path remains active if the end point vehicles do not move to a different road segment than the current one. If any of the endpoint vehicles move to another road segment, the gateway vehicle of previous road segment finds it out from the road segment routing table as the table is updated periodically. The gateway vehicle sends a destination discovery request to all other GVs on connected roads. The GV on the same road as the destination vehicle replies to the destination discovery request. The old GV updates the path from source to destination and sends it to the source vehicle to use the new active path in the transmission. Since the source vehicle does not have to start a new destination discovery request, a huge amount of network bandwidth is saved.

Gateway vehicles help adjusting the connected path without employing new path discoveries even if the end point vehicles change their moving speeds and/or directions.

4 Evaluation and Results

4.1 Simulation Setup

In the experiments to evaluate the CTQR protocol, version 3.18 of the ns-3 simulator [15] is used with the Two-ray ground model. The communication range of a vehicle is 250 m. The vehicle speed is in the range of {18, 120} km/h and the data packet size is 512 bytes. The evaluated protocols are: AODV, GPSR, and the CTQR protocol.

Presented results are for three different vehicle densities: low (less than 20 vehicles/km of road), medium (30-40 vehicles/km), and high (more than 50 vehicles/km) in two movement scenarios: highway and city. 10 CBR traffic sources with a sending rate of 5 packets/second are considered. Sources stop sending data packets 30 seconds before the simulation end. Source/sink nodes neither leave the simulation area nor park anywhere in the map during the simulations (300 seconds). The details of simulation parameter can be found in Table Ⅳ. Figure 11 shows an illustration of road map and vehicle distribution on the roads in the simulations. The red dots represent vehicles on the road.

Table IV: Simulation parameters

Parameter	Value
Simulation Scenario	Roads with multiple intersections
Propagation model	Two ray ground
Simulation area	3000m x 3000m
Traffic pattern	CBR
Packet size	512B
Simulation time	300s
Communication range	250m
Vehicle speed	18 to 120 km/h
Transmission power	21dBm
Mobility model	IDM
Lane change model	MOBIL
Transmission rate	6Mbps

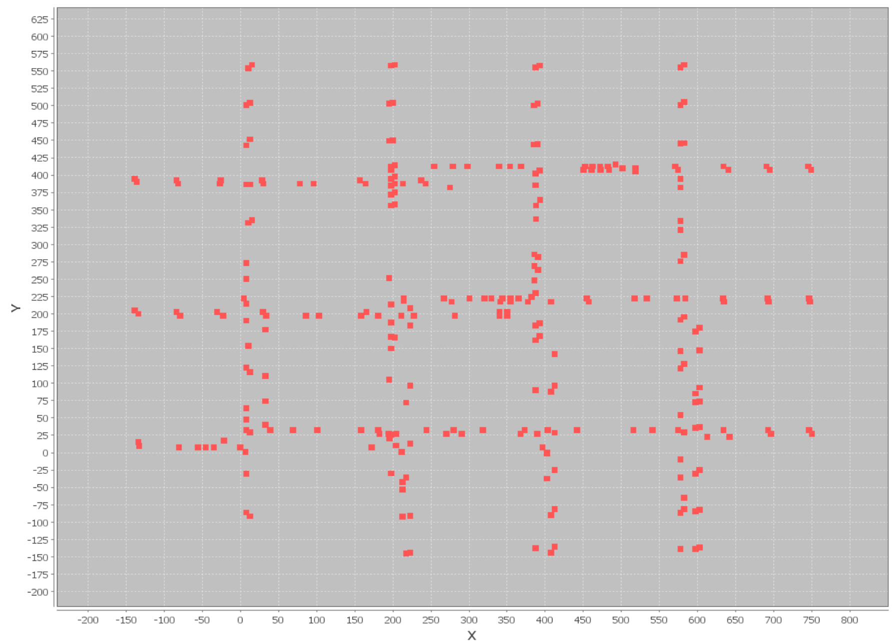

Figure 11: Snapshot of vehicles from the simulations

4.2 Evaluation Metrics

Following metrics are presented to compare the performance of the evaluated protocols.

4.2.1 Packet delivery ratio: The fraction of data packets sent by the source that are received by the destination

4.2.2 End-to-end delay: The time required for the data to reach the destination vehicle from the source vehicle

4.2.3 Routing overhead: The number of routing packets transmitted per data packet delivered at the destination

4.2.4 Link failure ratio: The ratio of total number of sent packets to the number of packets dropped due to link failure.

In order to find the optimal values for α in equation 6, simulations were performed and its effect on protocol performance is given in the following section.

4.3 Simulation Results

4.3.1 Packet delivery ratio

Figure 12 and Figure 13 show packet delivery ratios for city and highway scenarios respectively with three different densities of vehicles. For all traffic densities, AODV performs very poorly in the city scenario, with 12-13% of data packets delivered. Also, GPSR shows better performance than AODV (around 21% delivery ratio) but shows lower delivery ratio than CTQR. Despite the additional overhead to maintain road segment routing table and to discover the destination location and path, CTQR demonstrates much better results than GPSR. The highway scenarios are geographically less sophisticated than the city scenario: therefore, all studied protocols show better PDR in highway scenario. Again, CTQR outperforms AODV and GPSR, despite the need to obtain and maintain paths between source-destination pairs.

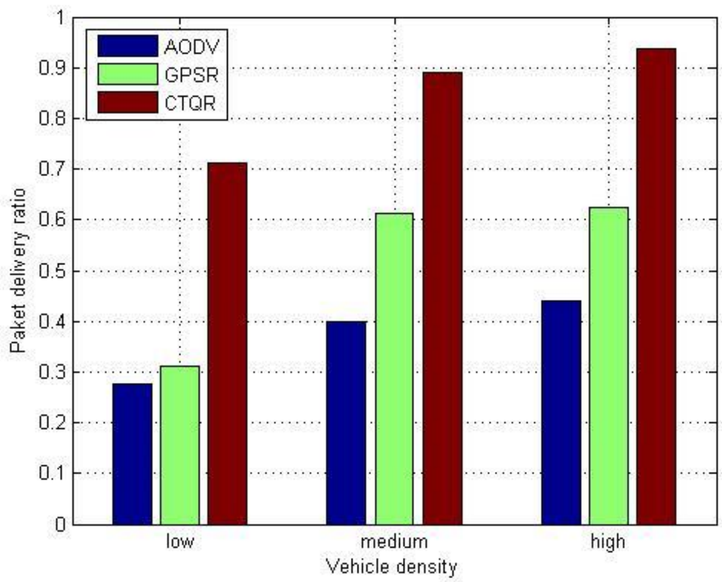

Figure 12: Packet delivery Ratio (City Scenario)

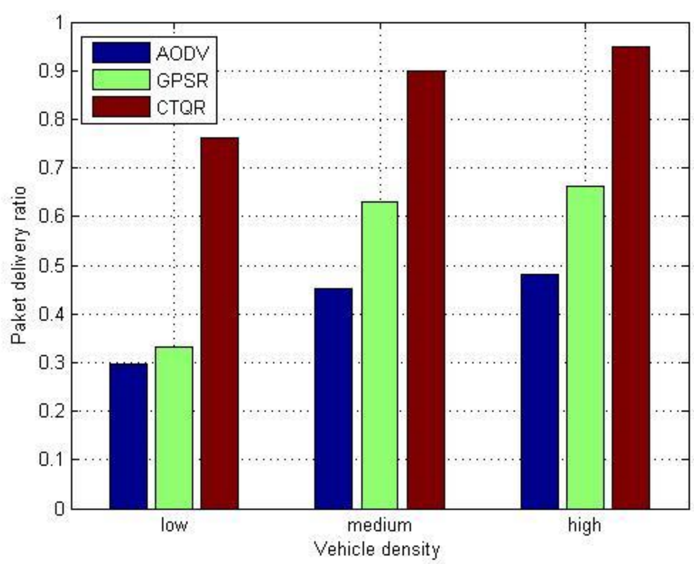

Figure 13: Packet Delivery Ratio (Highway scenario)

4.3.2 End-to-end delay

In terms of the average end-to-end delay (Figure 14 and Figure 15), AODV and GPSR are worse than CTQR in both scenarios (city and highway). In CTQR, the path discovery process precedes for the first time a data transmission is required between two vehicles. This step adds delay for the first packet. However, once the source vehicle finds out the path, it is maintained by the gateway vehicles. Therefore, the delay is very low for the data packets after the first one.

The average end-to-end delay of the data packet for CTQR is much lower than for AODV and GPSR. This result is a consequence of CTQRs use of real connected paths between source and destination vehicles, whereas, GPSR often fails due to resolution of local maximum handled by the perimeter mode. Furthermore, each time a path fails between source and destination pairs, AODV starts a new discovery process which adds a huge amount of delay in the packet delivery process. CTQR handles short-term disconnections very easily due to the use of gateway vehicles. In the scenarios with low density of vehicles, the network often becomes disconnected, which leads to a low PDR and high end-to-end delay for all the tested protocols. However, it can be clearly seen that CTQR outperforms other two protocols in both metrics.

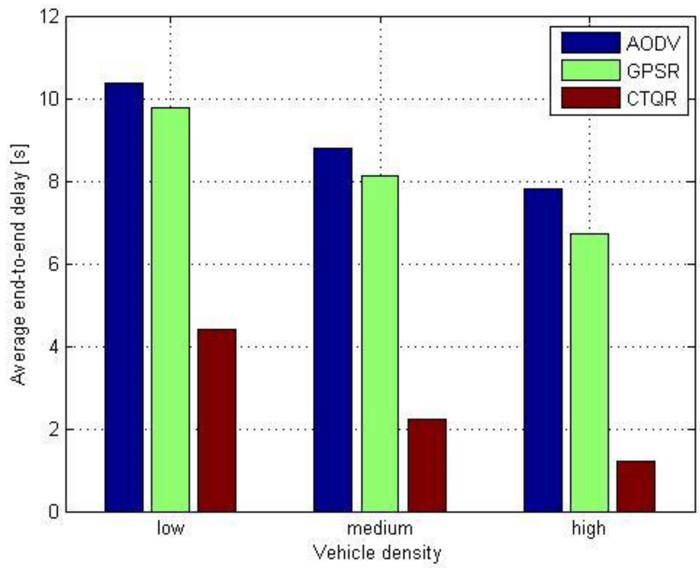

Figure 14: Average End to End delay (City scenario)

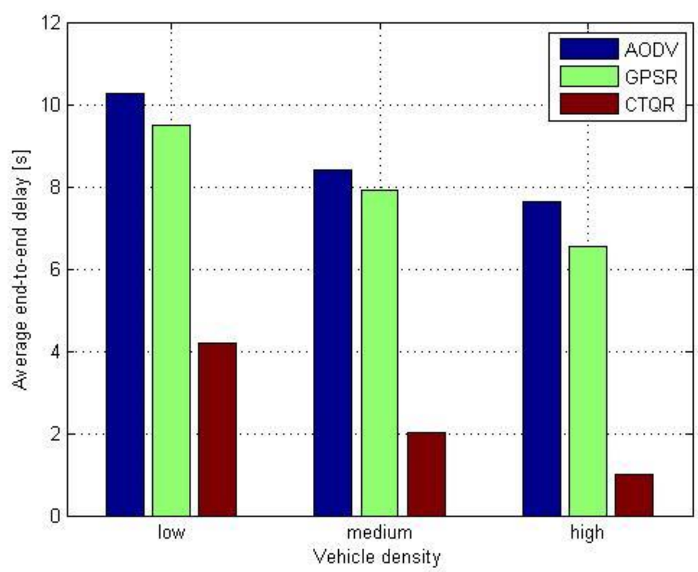

Figure 15: Average End to End delay (Highway scenario)

4.3.3 Routing overhead

The normalized routing overhead is presented in Figure 16 and Figure 17. Routing overhead of AODV consists of the destination discovery, whereas, in GPSR periodic beaconing contributes mainly to the routing overhead. Destination discovery process in AODV consists of broadcasting the packet to all the nodes in the network. However, in CTQR, there is no broadcast for the destination discovery process. Discovery packets are sent only to the gateway vehicles. In GPSR, the routing overhead caused by the failed paths contributes significantly to the degraded performance. It can be seen from the evaluation results that CTQR generates less routing overhead than other two protocols in both scenarios. It is mainly because CTQR does not use broadcasting of destination discovery and it does not start a new discovery process each time a path disconnects.

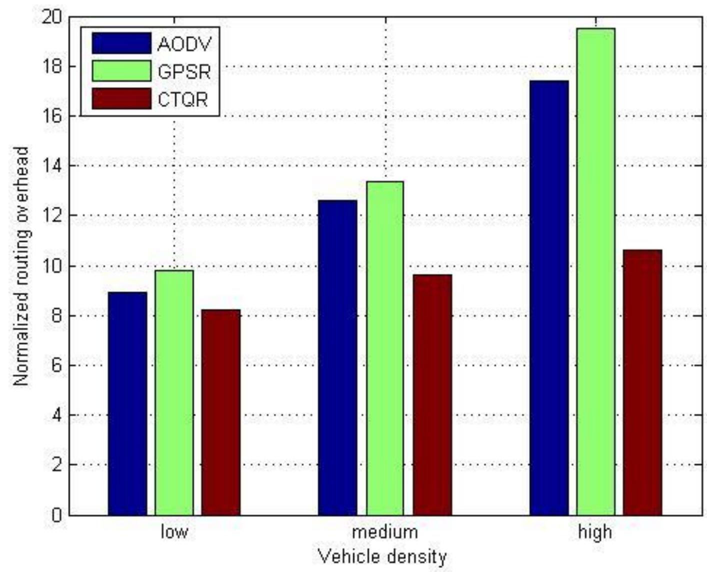

Figure 16: Normalized routing overhead (City scenario)

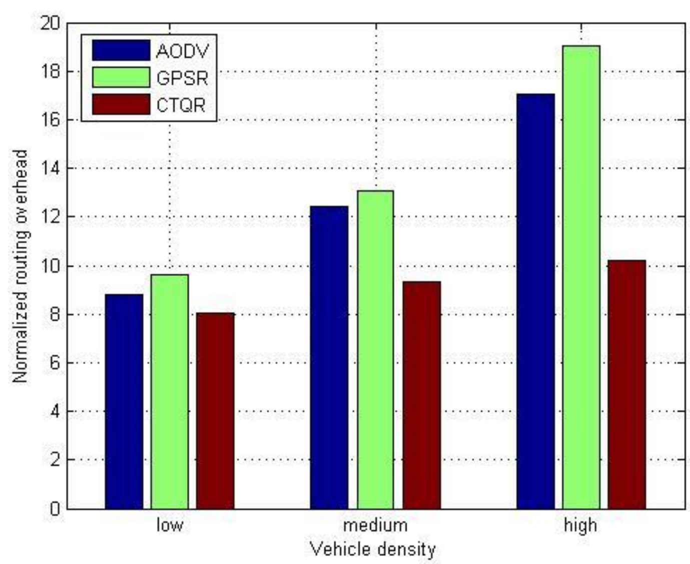

Figure 17: Normalized routing overhead (Highway scenario)

4.3.4 Link failure ratio

Figure 18 and Figure 19 show the link failure ratio for city and highway scenarios respectively. AODV and GPSR have more link failures as compared to CTQR. This is because each time a link fails; AODV and GPSR find a new path from source to destination. Due to the proactive routing between intersections, CTQR can shift the data forwarding to other available paths in case of link failure. Furthermore, CTQR forwards data on the most reliable path calculated by the GVs. Therefore, CTQR has much higher performance than AODV and GPSR in this metric.

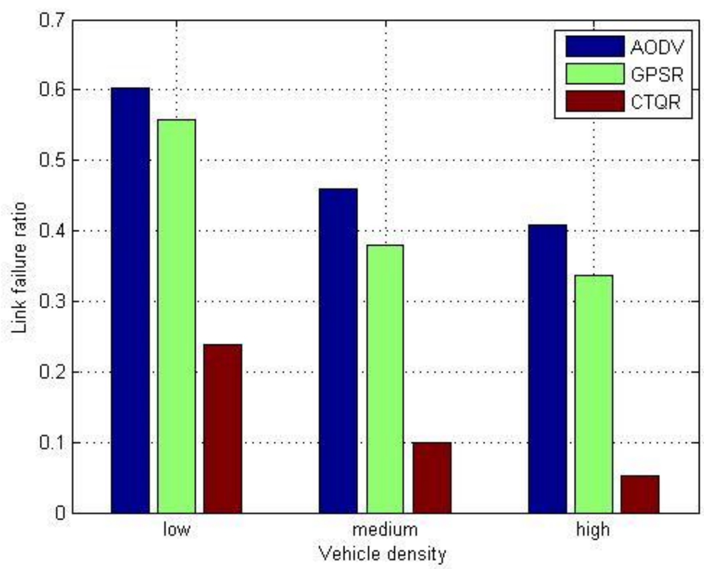

Figure 18: Link failure ratio (City scenario)

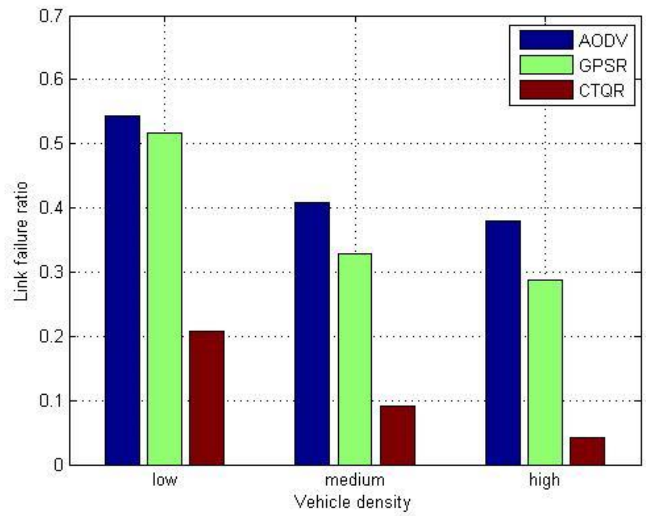

Figure 19: Link failure ratio (Highway scenario)

4.3.5 Effect of α on protocol performance

Effect of α from Eq. 6 on the performance of protocol is presented in Figure 20. The figure shows effect of different values of α on delivery ratio and network routing load. Delivery ratio remains close to 90% when $\alpha < 7$ and it decreases when alpha is increased beyond that value. In the simulations, optimal value of α used is 6 as it can be seen from the figure that delivery ratio is maximum as well as routing load is less than 30% for this value.

The optimal value of α in this thesis is specifically for the road network that is used in the simulations. The optimal value presented cannot be used as a general value for α because the performance of the protocol differs with different roads and conditions.

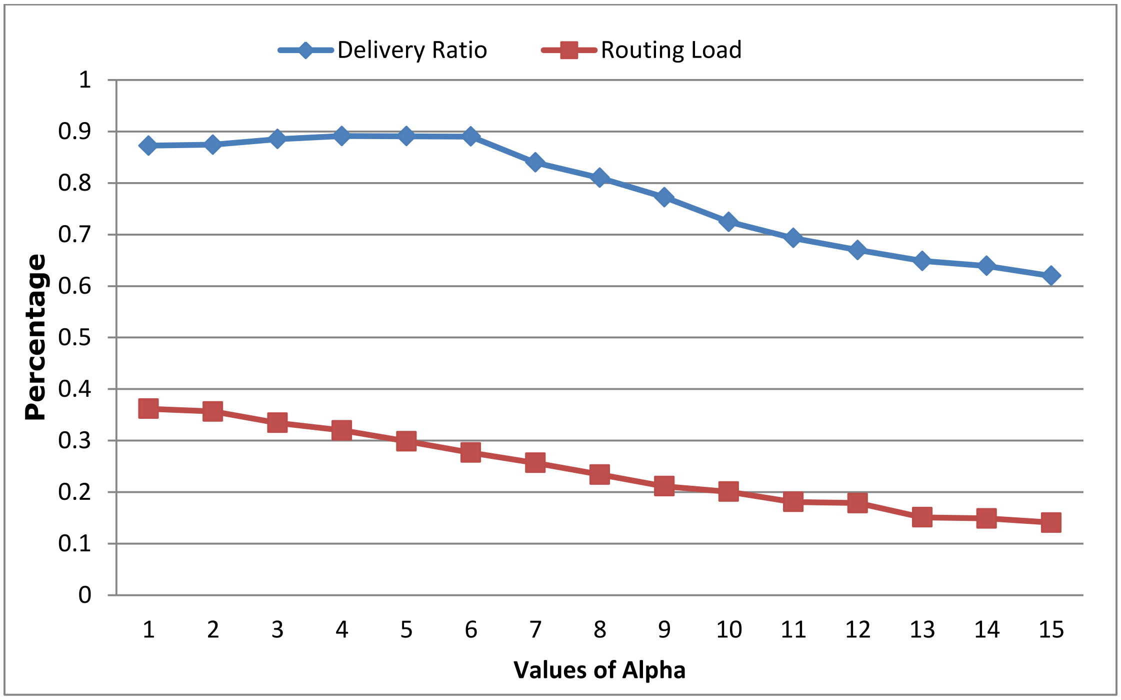

Figure 20: Effect of α on protocol performance

5 Conclusion and Future Work

VANETs have the potential to provide very interesting applications. These applications include but are not limited to road condition warning, parking spot finder, traffic congestion warning or multimedia applications. To efficiently utilize the network resources, routing of data packets is important because with the accurate choice of routing protocol, network routing load on the resources can be minimized. The routing protocol presented in this thesis is designed to keep the routing load to a minimum. Therefore it has many applications that can be integrated with the protocol.

Applications that disseminate small information to larger areas such as, road condition warning system need the data to be aggregated before starting its transmission. The data from a group of sources is combined and fused while keeping its meaning to maximum in order to reduce the bandwidth utilization [21]. Integration of the applications that use data aggregation with this context-aware multi-level routing protocol is one of the major tasks that need to be done in the future. Since aggregation provides reduced bandwidth utilization, same is being done by the routing protocol presented in this thesis. By combining both techniques, many VANET applications can be supported specially those which disseminate the data to large and far away areas.

Hovering information [22] allows the data to be logically attached to a geographic area instead of storing it on a physical server. There have been many proposed studies [23], [24], [25] about how the information should hover in the area but none of the existing studies propose routing technique for the information. The context-aware routing protocol can be combined with information hovering applications in order to make these applications more realizable in a VANET. In hovering information, a source generates a piece of information and attaches a geographic location to it called the anchor area or anchor zone. The information is then forwarded towards the anchor area and it is disseminated inside anchor area once it reaches there. The routing of this type of information with a low routing overhead is necessary which I believe can be provided by using context-aware routing protocol presented in this thesis.

In the context-aware beaconing section, the context of vehicles is determined by the neighbors and speed of vehicles. The definition of vehicular context can be extended further in future by adding more parameters. These parameters can include location, direction, and other road related information that directly or indirectly affects vehicles context. By adding more parameters in defining context of vehicles, the performance of this protocol can be further improved.

VANETs help in passenger safety and other multimedia applications. Implementation of VANET applications is just around the corner as a few of automobile manufacturers have already introduced car to car communication in real world. It is just a matter of time when we will be able to see VANETs helping cars and passengers in terms of road safety.

This thesis presents CTQR, a novel Context-aware Two-level QoS Routing protocol for VANETs. CTQR uses characteristics of both types, proactive and reactive routing protocols to provide a scalable low overhead routing algorithm with efficient delivery ratio for inter-vehicle communication both in city and highway scenarios. CTQR is able to locate the destination without using a location service. Rather than using a broadcast to discover the destination and active path, CTQR uses an efficient scheme that reduces routing overhead and end-to-end delay with successful delivery of packets. It uses an efficient context-aware beaconing scheme that utilizes the context of vehicles and reduces the routing overhead. Neighboring vehicles and vehicle speed is considered for the context of vehicles. Routes are maintained on the fly by the gateway vehicles to avoid a new discovery process from the start. Once a vehicle knows about its surroundings and local road segment routing tables by the use of context-aware beaconing, the weights for each available path are calculated in order to ensure QoS. The evaluation results show that CTQR outperforms GPSR and AODV in multiple performance metrics.

VANETs must deal with the always changing node topologies, and a number of other issues must be addressed before VANETs can be deployed in real world. CTQR addresses one of the key issues in the design and deployment of VANETs. Evaluation results in this study suggest that using the concept of a hybrid routing protocol with the use of gateway vehicles can significantly improve the performance of a routing protocol.

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