Load Balanced VANET Routing in City Environments

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***Abstract*— To conquer VANET applications requirements, many routing protocols have been proposed. Most of them have focused on geographical routing because of VANETs specifications. Many of which have tried to find connected paths through the network, by forwarding the vehicular traffic towards paths with higher connectivity probability. Once all the nodes in the network use this same routing strategy, it will eventually lead to great amount of data traffic on particular higher rated roads. Therefore, higher congestion and drop ratios will occur on those roads. This means unbalanced data traffic distribution throughout the network which is the main concern of our proposed VLBR (VANET Load Balanced Routing) protocol in this paper. VLBR aims at balancing the traffic between all potential connected paths by attaining congestion feedback from the network and switching to lower congested routes by utilizing the k-Shortest Paths algorithm. The simulation results imply improved delivery ratio and throughput compared to other VANET protocols. Contrary to other routing mechanisms, VLBR maintains its high delivery ratio even in great traffic loads without imposing extra overhead to the network.**

Keywords-density aware; k-Shortest Paths; load balanced vehicular routing

I. INTRODUCTION

Vehicular Communications are becoming very popular as a necessity for Intelligent Transportation Systems. This kind of communications support many types of mobile distributed applications, mainly categorized into the following three classes: traffic, safety and entertainment applications. Obtaining information about parking lots or nearby restaurant services, road traffic information and even multi streaming and gaming are a few to name.

All of the applications mentioned above, either need the vehicles to connect to an appropriate gateway in their neighborhood in order to access the backhaul internet, or to connect to other vehicles in their vicinity. Since the roadside units are not sufficient to guarantee infrastructure based communications, multi-hop transmissions become essential. Moreover, an ad hoc network architecture is needed to support proper transmission between nodes. This architecture is known as the Vehicular Ad hoc Networks (VANET) which is the focus of this paper.

To overcome the requirements of the various applications, deployment of an efficient routing protocol that would assure maximum delivery ratio and robustness through the highly dynamic environment where vehicles have high speeds and change their positions constantly, is necessary. Traditional MANET routing protocols such as AODV[1], DSR[2], don't perform efficiently, mostly because of the instability of the routes they find. As [3] illustrates, position based routing mechanisms such as GPSR[4], GSR[5] seem to be the best options. VANETs carry specific features that make their routing distinct from other ad hoc networks and thus must be considered when planning new routing strategies. High speeds in vehicular networks result in frequent disconnections and rapidly changing topology of the network. Therefore designing routing protocols with stable routes is the most important issue in VANETS. Furthermore, movement of vehicles is affected by driving restrictions, road barriers and driver behaviors. Also, obstacles such as skyscrapers cause disconnections in wireless signals. Due to all of this, communications between vehicles must be line of sight and according to [6] since vehicle movements are limited to restrictions, the VANET topology consists of all the roads containing vehicles. Thus optimal routing in VANETs means finding the road path with the highest probability of delivery ratio and throughput.

Another important issue not considered in recent investigations, is the problem of load balancing in vehicular networks. Proper traffic distribution between all potential connected paths of the network means lower drops caused by congestion and thus higher throughput.

Sensing the lack of load balancing in VANETs, we have proposed our new VLBR adaptive routing protocol. VLBR finds the k-Shortest Paths between each source and destination willing to have a communication with the use of the cost model proposed. When forwarding packets, VLBR distributes the load between all intermediate nodes by choosing the next hop according to road conditions, either to nodes with the same moving direction or those with lower collision probability. During the connections, the protocol warns about path congestions when confronting prior congestion threshold. In such cases, related connections could switch to less congested paths. As a result, the traffic load will be balanced throughout the entire network and VLBR will gain higher packet delivery ratio and throughput.

In the rest of the paper we will first take a look at the previous work done on VANETs in section II. Afterwards we will propose the VLBR protocol in section III. The simulation results and performance evaluation will be presented in section IV and section V will conclude the paper.

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II. RELATED WORK

Routing protocols in VANET are classified as topology based and position based. Topology based protocols need link information to determine an end to end path between each source and destination in order to forward packets. But since VANETs have highly dynamic structures, routes found are subject to breaks and repairing overhead is high ([7][8]). Therefore, position based routing protocols also referred to as geographical protocols are highlighted. In geographical routing each node chooses the next forwarding node according to its neighbors and the destinations location. Each node's neighbors are defined by the periodic hello messages sent. Geographical routing relies on each node knowing its own position and the packets destination location which is not an ideal condition because of the increased popularity of on board GPS navigation systems on cars. Moreover, location service management protocols provide node positions in a short instant [9][10]. Most of the geographical routing protocols also assume that nodes have road maps of the city and are able to map their GPS position on to the map. With all the above assumptions, protocols such as GPSR[4], GSR[5] have addressed this kind of routing. GPSR uses greedy forwarding to send packets, so it might get stuck in local optimums because of city obstacles. Even the perimeter mode might not be able to help in such situations and can fall in loops. GSR uses the road map to find the shortest path of intersections between the source and destination. Greedy geographical routing is used to traverse between intersections on this path. MORA[11] is another protocol in which the direction of a moving vehicle and its distance to the destination together determine a metric. Vehicles forward packets to neighbors with the highest metric value. In Spatially Aware Packet Routing protocol [12], a graph is built in accordance to the roadmap, in which intersections form the vertices and roads form the edges. The Dijkstra algorithm is used to find the optimal path on the obtained graph. None of the routing strategies mentioned, take vehicular traffic information into account, therefore connectivity aware routing protocols were proposed. A-STAR[13] is one of such protocols which uses bus line paths to find the most connected paths. However, pushing the traffic to the most connected roads will result in more transmission traffic, congestion and thus packet loss on those roads. VADD[14] considers both the average vehicular density and velocity to find the next forwarding junction. VADD intends to minimize end to end delay, however doesn't show high performance in dense conditions. [3] tries to contemplate real-time traffic information by proposing two routing algorithms named RBVT-Reactive(RBVT-R) and RBVT-Proactive (RBVT-P). RBVT-R is a source routing protocol that finds a route to the destination by flooding a request towards it. Once the destination replies back, geographical routing is used to forward packets through the sequence of intersections defined in the reply packet header. On the other hand, RBVT-P tries to discover the topology of the connected roads and disseminate this information to other junctions, so they can use shortest path routing to forward packets. Although this paper tries to consider connectivity to some extent, it doesn't perform well in sparse networks because of high repairing overhead. Also it has a high routing overhead and the information used is not very up to date. In [15] each road is divided into clusters according to the transmission rage of vehicles. Each cluster head sends the clusters traffic information to its respective intersection. This protocol tries to provide vehicles with vehicular density of approaching intersection's roads. It does this by collecting density information at roads and forwarding it to vehicles in the vicinity of the intersection by multi hop transmission. Each vehicle arriving at the intersection looks at the neighboring intersections in the map and calculates a score for each one according to the density information and distance to the destination. Whichever intersection receives the higher score, will be chosen as the next hop. Although this algorithm tries to take the connectivity and real time traffic into account, it still suffers from being greedy and not reflecting the load effect. This will eventually push all the traffic to higher density roads. Although ACAR[6] and GyTAR[15] try to perform adaptively with the network situation, they still don't have any recovery strategies when encountering congested areas where packets cannot be forwarded because of collision and congestion on nodes. Furthermore, they just represent recovery approaches when next hop forwarding nodes are not found. To conclude, none of the routing protocols presented have issued the load balancing problem. Works such as [16][17] focus on load balancing on road side units (RSU) and not in the entire network. If the closest RSU is not capable of providing sufficient bandwidth for the connection, packets are relayed to other RSUs. Also a couple of mechanisms were presented to distribute load between relaying nodes. Though, end to end load balancing is still not guaranteed. Our VLBR protocol not only considers connectivity, but also takes into account network congestion and collision to provide load balancing facilities. The next section will explain the protocol with more details.

III. VANET LOAD BALANCED ROUTING PROTOCOL

To propose VLBR, we consider the following assumptions which are commonplace in most VANET geographical routing protocols. First, each node is aware of its geographical position and can map this position on its preinstalled roadmap. This is a rational assumption considering the installed GPS systems on vehicles. Also we assume that the road maps not only contain the road information, but also consist of information about each road's vehicle density at certain times of the day. Periodic updates about the density can either be obtained from traffic centers or with mechanisms such as the ones proposed in GyTAR and A-CAR which are not the consideration of this paper. However, as the traffic distribution of vehicles does not change very rapidly throughout a specific time, the updates are not frequently needed. Furthermore, as VLBR is an adaptive protocol, it is not highly dependent on accurate road density information. With these assumptions we can now map the road network onto a graph, in which the intersections make the vertices and the roads form the edges of the graph.

VLBR uses the following three phases to route packets towards their destinations. In the first phase, each source vehicle determines the optimal list of intersections between itself and the destination and places this list in the header of each packet and forwards it towards the first intersection. The second phase is the forwarding decision that each intermediate node makes to forward packets between intersections. And the final phase is to obtain feedback from the network and switch adaptively to superseding paths in case of pre-congestion observation in the determined path. We will explain each phase in more detail in the following subsections.

A. Finding the Path Between a Source and a Destination

VLBR is a source routing protocol in which each vehicle wishing to send a packet should define the route in the header of the packet prior to sending. First, each source vehicle obtains the destination's location from the location server managers. Then, it finds the optimal sequence of intersections that should be traversed towards the destination from the road map. This sequence is placed in the header of the packet and the packet is forwarded to the first intersection. As Most communications in VANETs eventually connect to the backhaul Internet through RSUs, the sequence of intersections is not large compared to the header of the packet.

Previous research such as [5] and [12] have utilized shortest path routing to determine the sequence of intersections, but weren't very successful since the vehicular density was not taken into account. To point this problem, we have developed a new mechanism in which the cost of each edge is defined according to the related road's density and length. This means a vehicle wishing to forward a packet, will find the shortest path (the path with the least distance and most density) towards the destination. This function is defined as below.

$$Cost_{i,j} = \alpha \,. f(l_{i,j}) + \beta \,. g(d_{i,j}) \tag{1}$$

Where $Cost_{i,j}$ determines the weighted cost of each edge(i,j), dependent on $f(l_{i,j})$, a function of its length, and $g(d_{i,j})$, the function of road density. $f(l_{i,j})$, is calculated using the following equation.

$$f(l_{i,j}) = \frac{l_{i,j}}{\max \{l_{i,j} | i,j \in V\}} \tag{2}$$

Where $l_{i,j}$ is the road's length and V is the graphs set of vertices. In order to normalize $f(l_{i,j})$, the length of each road is divided to the maximum road length.

On the other hand, we have the traffic density function $g(d_{i,j})$, which illustrates the connectivity of the road, i.e. the higher the density on the road, the higher the probability of connectivity will be on that road. So this link will have a lower cost and thus, is more probable of being chosen as one of the links in the shortest path route. To determine the proper value for this function, we need to know the least number of vehicles required to assure connectivity. In [15] the ideal connectivity degree is found for this purpose. Assuming R to be the radio communication range, it presents the probability of continuous connectivity as a function of the average number of vehicles per cell. Each cell's radius is R. This paper proves that having a radio communication range of 250 m (802.11 standard), we can achieve a probability of connectivity near 1, by only having 12 vehicles per cell. We used this definition to find the average number of vehicles per road to assure connectivity ($N_{connectivity}$) as follows:

$$N_{connectivity} = \left\lceil \frac{l_{i,j}}{2R} \right\rceil . 12 \tag{3}$$

We can now define $g(d_{i,j})$ such that:

$$g(d_{i,j}) = \max(0\,, 1 - \frac{d_{i,j}}{N_{connectivity}}) \tag{4}$$

$d_{i,j}$ illustrates the average traffic density on $edge(i,j)$. Since traffic density has an inverse relationship with link cost, the value is subtracted from 1.

Having more vehicles than the number required to assure road connectivity, will not increase connectivity. Therefore, if there are sufficient vehicles on the road, the main cost is caused by the distance to the next intersection which determines the delay of packet delivery. This is the reason of using the maximum function in $g(d_{i,j})$. That is, if connectivity is assured, density will not affect the cost. Hence

$$Cost_{i,j} = \alpha \,. f(l_{i,j}) + \beta \,. g(d_{i,j}) \tag{5}$$

$$= \alpha . \left(\frac{l_{i,j}}{\max \{l_{i,j} | \, i,j \in V\}} \right) + \beta . \left(\max(0\,, 1 - \frac{d_{i,j}}{N_{connectivity}}) \right)$$

B. Routing Between Intersections

After the sequence of intersections is determined, packets are routed between intersections. But how should each intermediate node forward packets? We observed that greedy forwarding strategies such as GyTar don't perform well since packets might be carried back and forth in sparse situations or even carried out of their assigned route. Thus, in our strategy each node that receives a packet will look at the road it is placed on. According to the road's density, the node will either consider the road as sparse or connected. If the road is considered to be sparse, the node will forward the packet to a neighbor that is moving towards the next intersection to prevent the ping pong movement of the packet. And if the road is considered connected, then the node will choose a neighbor that is closest to the next intersection and has less collision probability compared to other neighbors. To have an estimate of collision probability, we have used the IEEE 802.11 contention window conception. When sending data in IEEE 802.11, the node listens to the channel. If the channel is sensed idle, it will start sending its data. But if the channel is busy, it will back off for a random number of slots between $(0\,, CW)$. The contention window starts with $CW = CW_{min}$ and doubles with every retransmission effort until it reaches $CW = CW_{max}$. As the number of transmissions increase, there will be more contention on the channel and thus the back off values will be higher. Therefore, we update the collision probability of each node when a transmission takes place with the following weighted equation:

$$Coll_i = \alpha \,. Coll_{i-1} + (1 - \alpha) CW_{curr} \tag{6}$$

$Coll_i$ is a suitable measure of traffic load on intermediate nodes. This measure is piggy backed alongside the node's speed to neighbors in the transmission range. So it will not impose extra overhead. This way the traffic will be dispersed between all intermediate nodes.

C. Balancing Traffic Using k-Shortest Paths

If we only find the shortest path using the cost function in (5), after a while of sending data, the traffic load on higher density roads will increase. This will lead to higher congestion probability and more loss and unbalanced load distribution. Therefore, we replaced the shortest path routing with the k-Shortest Paths algorithm [18].

The k-Shortest Paths algorithm lists the loop less k minimum cost shortest paths for a given source-destination in a directed graph. Applying the k-Shortest Paths here means despite having the path with most density and least distance cost, we will have the second, third,…, k best routes too. The k-Shortest Path algorithm is run by each vehicle prior to sending a packet. As the complexity of this algorithm is $O(m + n \log n + k)$ and the graph of city roads is a sparse matrix with each node connecting to at most 4 neighbor intersections, applying this algorithm will not impose heavy computational complexity.

After finding the k-Shortest Paths route towards the destination, packets are forwarded on the 1st shortest path according to (5). This is shown in Fig.1 where the vehicles with same color want to start connections with each other (n2 to n6, n3 to n5 and n1 to n4). This means they will all be sending packets using road (I3, I7). Throughout the route, packets are forwarded to nodes with the least collision probability. But if all the nodes on the road have a collision probability higher than the predefined threshold, we are probably facing a heavy loaded area where a lot of transmissions are taking place and thus we are probably approaching the congestion situation. Therefore, VLBR sends a "congestion warning packet" to the source of the connection to switch to another less congested path. As the warning packet is a small packet, it can be sent to the source with the GPSR algorithm. Once the source receives the packet, it will start a timer and switch its route to the 2nd shortest path (the purple and yellow dotted lines shown in Fig.1). This way, it prevents packet loss due to congestion on the 1st shortest path, and reduces the load on the previous more attractive path. The second path is used until either a new warning packet is received or the timer expires. The timer is to route packets back to the attractive paths because of two main reasons. First, other connections might have backed off when sensing collision on the route. Therefore its load has probably decreased after some time. Second, the network's data traffic distribution might have changed due to cars movements.

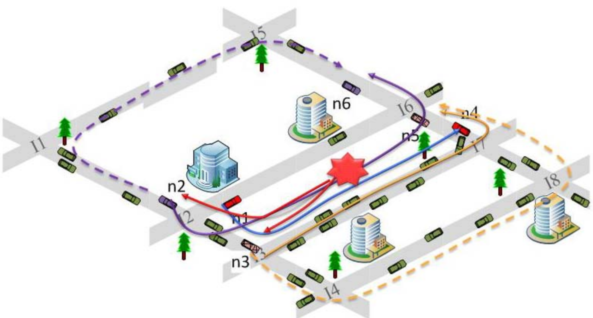

Figure 1. VLBRs load balancing mechanism

The timer strategy gives us the opportunity to further inspect the network and routing back to best routes will provide us with this inspection.

Another important issue is that, when a node senses the congestion, it will send the warning with some probability. This is because, if all the connections change their route, this path will suddenly be vacant and the bandwidth of this optimal route will be left unused. As a result, all the connections sensing congestion won't be subject to route redirection.

IV. PERFORMANCE EVALUATIONS

To evaluate the performance of the proposed protocol, we implemented VLBR in ns 2.33[19] and used SUMO[20] to simulate the vehicular movement in VANETs. The log file produced by SUMO is taken as input into MOVE [21]and is converted to a trace file which could be used in ns-2.

In the simulations a grid layout of approximately 1500x1500 square meters was used. More details about the wireless and movement parameters are shown in Table I. To evaluate VLBR, we used the packet delivery ratio, throughput and average number of sent packets per received packet measures throughout the simulations. "Packet Delivery Ratio" shows the ratio of received packets in higher layers, to packets sent into the network from higher layers. "Throughput" is the successful message delivery over time. And, "Average Number of Sent Packets per Received Packets" is the ratio of packets sent in the network either from higher layers or network layer (due to retransmissions or collisions) to the packets that were delivered to the higher layers. This measure shows the average traffic load sent to the network for each successful transmission.

As none of the protocols proposed have considered load balancing in VANETs, we will compare our results with that of GPSR and GPSR* (GPSR with carry and forward), which have shown to perform well in regular situations where the road map is not too large or too sparse. An outstanding feature of VLBR is that its load balancing strategy can be applied to other source routing protocols and could make the same improvement to them. This could be done by applying the k-Shortest Path selection instead of the best selection and switching to superseded routes in congested environments.

TABLE I. SIMULATION PARAMETERS

Simulation area	$1500\ m \times 1500\ m$
Average road length	$500m$
Lanes per road direction	2
Number of vehicles	40-150
Vehicle speeds	15-60 km/h
Simulation time	300 sec
Transmission range	$250m$
Traffic model	10-35 cbr connections
Data packet size	512 bit
Beacon interval	3 beacon/second
MAC layer	IEEE 802.11

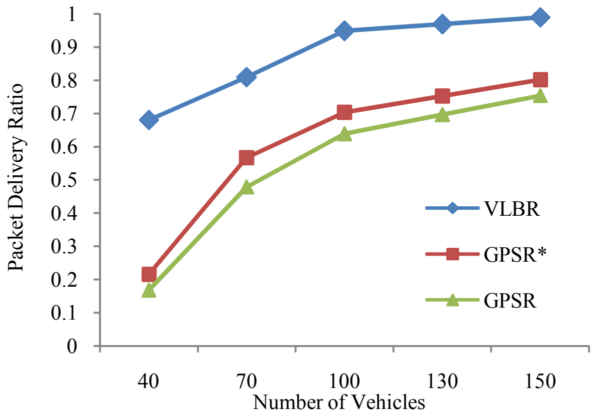

Figure 2. Impact of network density on packet delivery ratio

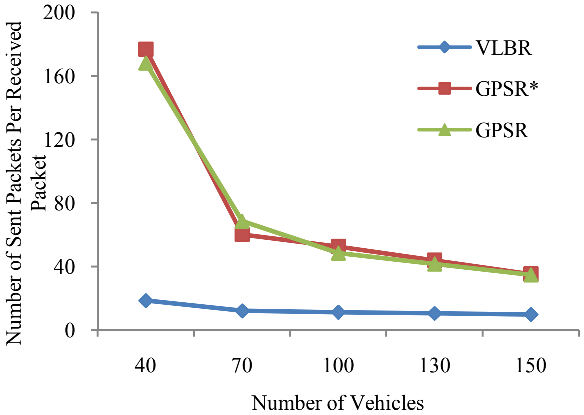

Figure 3. Average number of sent packets per received packet

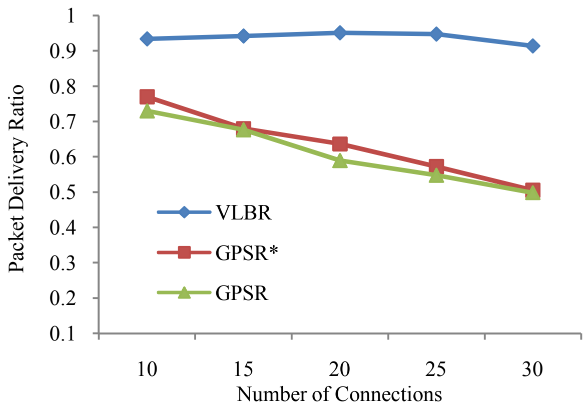

Figure 4. Impact of number of connections on packet delivery ratio

A. *Network density effect*

One of the most important parameters that affect the performance of a VANET protocol is the number of vehicles in the network. Most of the routing protocols show higher packet delivery ratio with increase in this number [6]because of increased probability of connection. As Fig.2 shows, the packet delivery ratio in VLBR is much higher than that of GPSR and GPSR*, especially in sparse conditions where disconnections happen more frequently. Protocols are ought to use their recovery strategies in such cases. Although GPSR uses the perimeter mode as a recovery mechanism, it can't always guarantee connectivity, especially in sparse networks with frequent disconnections. On contrary, VLBR considers traffic density in path selection and forwards packets to routes with higher connectivity probability and shows higher delivery ratio.

To show VLBRs effect in reducing congestion, we have used the number of packets sent per received packets measure. Fig.3 shows that this parameter and thus the retransmission effort are much lower in VLBR comparing to the other two protocols. Retransmissions can be caused by high contention, route finding or recovery failures. In VLBR, paths are defined prior to sending packets and switching occurs in congested areas, so retransmissions occur rarely.

B. *Network load effect*

The most important goal of VLBR is to distribute traffic in networks with high load. To show the high performance of VLBR in balancing the traffic, we have analyzed the networks performance under different number of CBR connections. Fig.4 shows the packet delivery ratio for 10-35 connections in a network with 100 vehicles. As this figure implies, the delivery ratio of GPSR and GPSR* decreases with the increase in the number of connections. This is mainly because of their greedy forwarding mechanism which causes buffer overflows and increased collision and high congestion probability on attractive paths. But VLBR, preserves its high packet delivery ratio because of its load balancing mechanism in which it chooses the least collided nodes as next hops and switches to other routes as soon as congestion is sensed. As a result, the throughput of the network will also outperform that of GPSR and GPSR* in high congested situations (Fig.5). As the network is nearly connected with this number of vehicles, the carry and forward mechanism is seldom used. Therefore, the throughput of GPSR and GPSR* won't have significant difference in this situation. The last measure we analyze is the average end to end delay which is slightly higher in VLBR compared to the other two, as we expected. Fig.6 shows the delay distribution of packets. VLBR puts the most effort to deliver packets. When confronting congestion, this could mean sending packets from even longer disconnected roads with increased carry and forward durations. This might result in longer delays. On the contrary, the other two protocols simply drop packets in such occasions and won't make any effort. So, as we can see in the figure, VLBR has even less delays for the same number of packets received in the other two.

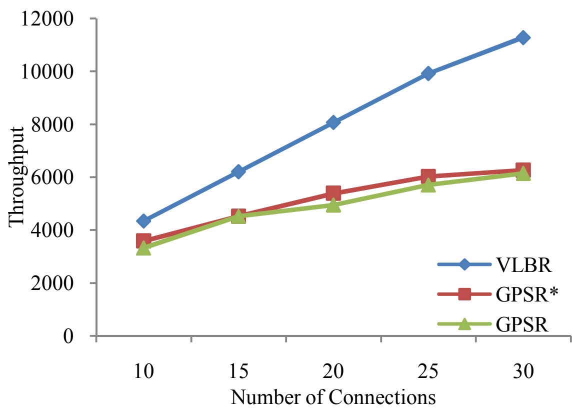

Figure 5. Impact of number of connections on throughput

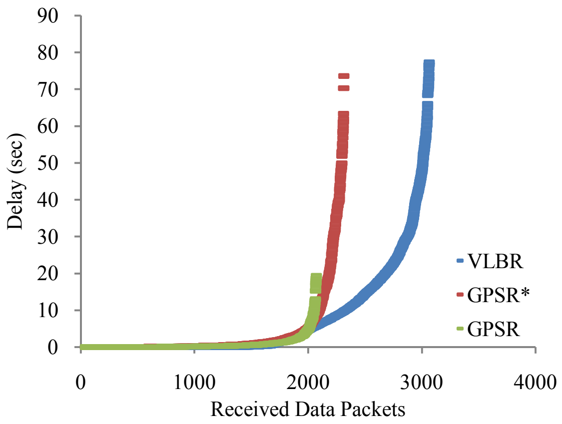

Figure 6. End to end delay

V. CONCLUSION

In this paper we proposed the adaptive, density and congestion aware VLBR source routing protocol. Each node finds more than one route between itself and the destination, prior to starting the connection and forwards the packets towards the first intersection. Throughout the route, each intermediate node forwards the packet according to the condition of the road. If the road is detected to be in pre congestion condition, a warning packet will be sent to the source, to change its route onto a lower loaded route.

If all the nodes of the VANET network perform the same routing strategy, the overall load of the network will be balanced between all connected paths. VLBR was shown to have the best delivery ratio and throughput through the simulations. Moreover, VLBR will impose the least traffic into the network and perform the best in high traffic loads. We will try to extend our work to detect the congestion with more parameters and present solutions to decrease the end to end delay in the future.

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