VELOR: Velocity-based Routing Protocol

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ABSTRACT

This research focuses on developing a velocity-based routing (VELOR) protocol for city and urban vehicular ad hoc networks. VELOR is a two-level routing protocol. The first level finds the intersections to be traversed along the routing path based on the road topology and vehicular traffic on each road segment. Selective flooding method is developed to reduce congestion and signaling overhead. At the second level, forwarding optimization is carried out using the standby function for selecting next-hop node based on the identified parameters. These parameters are the farthest predicted neighbor and the transmission probability. Simulations performed using Simulation of Urban Mobility (SUMO), BonnMotion and NS-2 compare the AODV, OLSR, GPSR and GOSR routing protocols with VELOR. VELOR shows as much as 35% increase in average packet delivery ratio and as much as 50% decrease in the average end-to-end delay as compared to the other protocols in high density, urban networks. On comparing across various mobility scenarios, the packet delivery ratios for all the protocols drop significantly with the increase in mobility model complexity, except for VELOR which is stable throughout. Across all the mobility models, the delays increase for all other protocols with increasing node density. However, for VELOR, the delay decreases.

Keywords

Velocity-based Routing; Realistic Mobility; Reactive Protocols; Vehicular Ad Hoc Networks

1. INTRODUCTION

Inter Vehicular Communication (IVC) networks are developed to facilitate people on the road with dynamic, real-time information and are realized through vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication. V2V networks are primarily used for safety applications such as cognitive awareness, collision detection and hazard identification, whereas V2I architecture aids applications involving traffic analysis and modeling. Although such Vehicular Ad Hoc Networks (VANETs) are a subset of Mobile Ad Hoc Networks (MANETs), their complex network architecture, multi-faceted applications and high node mobility physiognomies set it apart.

The rest of this paper is organized as follows. Section 2 reviews the existing literature. Section 3 explains the VELOR routing protocol in detail, while Section 4 evaluates VELOR's performance with other existing protocols and in various mobility scenarios. This paper is concluded in Section 5.

2. LITERATURE REVIEW

Mobility models are developed to explain the behaviour of mobile users by calibrating their acceleration, velocity and location changes over time. Since mobility models play a major part in determining the efficiency of a routing protocol, it is highly desirable that these mobility patterns closely replicate the realistic scenarios that are being considered, which is not the case in [1]**.**

All the existing routing protocols mentioned in [2] can be divided in two parent categories; routing for dense traffic and urban scenarios where the network is often connected and secondly, routing for sparse traffic and rural scenarios where network exists intermittently. Routing protocols for dense networks are implemented in urban areas with high vehicular node density and a next-hop node is always identified within current node's communication range. However, conventional routing protocols like Ad Hoc On-demand Distance Vector (AODV) [3] routing and Dynamic Source Routing [4] display low throughput rates when applied to practical vehicular traces as seen in [5]. Inspired by the implementation of GPS in vehicles, several position-based routing protocols have been developed [6-9] which utilize the geographic coordinates of neighboring nodes to construct the forwarding path. On the other hand, disconnections are frequent in highway, rural scenarios and urban scenarios at certain times (such as during night time), making the constructing of a stable connection almost impossible. Protocols in [10-12] have been developed for this. Some protocols also consider the road structures and forward data through the shortest route from source to destination.

3. VELOR PROTOCOL

The authors propose a reactive, two-level, velocity-based routing protocol, VELOR, which uses the traffic flow and road structure information to construct routes as a sequence of intersections based on their probability of connectivity in the first level.

3.1 Level 1: Path Discovery

3.1.1 Path Discovery Phase

The source creates a Path Discovery (PD) packet which contains the source location and address, destination address and a unique sequence number. The source broadcasts the PD packet to all the nodes around it (flooding) to construct a route to the destination. However, to reduce the congestion due to this kind of flooding, this protocol implements selective flooding. If any intermediate node receives the same PD packet again, i.e., with the same sequence number and source address, then the packet is discarded. On the other hand, when an intermediate node receives a new PD packet, it waits for a time interval proportional to the inverse of the distance between the sender and itself. Once this time interval elapses, it rebroadcasts the packet only if any of the other nodes located further have not rebroadcasted it. In some scenarios, the PD packet might reach nodes that are on parallel road segments. In such cases, the PD packet is not updated unless the intersections previously traversed can be determined. A limitation of such implementation is that since the entire path composed of various

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intersections is contained in the PD packet's header, the path length is limited by the size of each intersection address and header option size.

3.1.2 Path Confirmation Phase

Once the destination receives the PD packet, it will unicast a Path Confirmation (PC) packet to the source with the entire sequence of intersections that were traversed and its location appended to the packet header. The PC packet is forwarded along the intersections mentioned in the packet header and geographic forwarding is used on each road segment, between two intersections. It is possible that the destination node might receive more than one PD packets. But a PC packet will be generated only when the path in the current PD packet is better, i.e. less intersections to be traversed, than the current path. The source commences the sending of data packets once it receives the PC packet. The path confirmed in the PC packet is stored in the data packet header and geographic forwarding is used between the mentioned intersections.

a.

3.1.3 Path Maintenance Phase

Path breakages can certainly occur during forwarding between intersections, where the current node cannot find any next-hop node. When this happens, the node that experiences the issue, will unicast a Path Error (PE) packet to the source. In the existing literature, it is seen that such path breakages occur intermittently. Thus, the source waits for a predefined time-interval before initiating a new Path Discovery process. Once the affected node is back in service, it sends a notification to the source.

3.2 Level 2: Forwarding Optimization

Instead of placing the next-hop selection decision making in the current node, this task is distributed amongst all the nodes that are the candidates for next-hop node selection. This solution is inspired by the literature in [13-15]. As mentioned earlier, geographic forwarding is used between intersections. Whenever a node wants to forward a data packet it broadcasts a query control message to all its neighbors. Each of the neighbors calculates a standby interval based on the standby function (to be explained later). The neighbor nodes have to wait for their respective standby intervals to expire before they can select themselves to be the next-hop node. This addition of the standby time helps in the selection of the best candidate. If a neighbor node's standby interval elapses and still no other node is selected as the next-hop node, then it broadcasts its status as the next-hop node. This practice prevents control message congestion.

3.2.1 Next-Hop Selection

The authors use the RTS control messages in IEEE 802.11 Medium Access Control protocol [16] to broadcast the request to initiate the next-hop selection process to all the neighbor nodes. The current sender's and target destination's locations are appended onto the RTS frame. All the neighboring nodes compute their standby interval based on the standby function before they can broadcast their CTS frame. As mentioned earlier, this standby function is an objective measure of ranking the neighboring nodes and allowing the best next-hop node to reply first. Once a neighboring node broadcasts its CTS message, the other neighbor nodes that receive this CTS will quit this process as the best next-hop node has already been selected. The sender now forwards the packet to the selected next-hop node and this node replies with an acknowledgement.

3.2.2 Standby Function

This is the formula used to select the best next-hop node. The best neighbor’s computed standby interval should be the smallest in order to be selected first. Also, the difference between the time-intervals of various candidates should be considerably large to avoid collisions; whereas on the other hand the standby interval should be as small as possible to reduce transmission delays. The authors derive the below mentioned parameters.

***i. Farthest Predicted Distance (d_i)*:** This parameter is where the future location of a node is predicted using its current velocity. The distance travelled by the node in Tmax, the maximum permissible standby time, is calculated using its velocity. However, if the node traverses an intersection within Tmax, the probability of the various turns is extracted from the mobility model and is integrated into the calculation. The farthest predicted distance di is equal to dSD − dNiD, where dSD is the predicted distance between destination D and sender S, and dNiD is the predicted distance between destination D and current node Ni.

***ii. Transmission Probability (t_i)*:** This parameter is computed based on the current node's probability of reaching the vicinity of the destination node. This is the product of the probabilities of the current node turning towards the destination at each traversed intersection. If more than one direction can lead to the destination, the least probable one is selected for increased robustness.

Thus, integrating the above mentioned parameters into a single equation the following multivariable polynomial is derived as the Standby Function shown in (1).

$$f(d_i, t_i) = K\, d_i\, t_i + T_{max} \qquad (1)$$

The standby interval is bound to be within the range $[0, T_{max}]$ and $K = (-T_{max} / (d_{max}\, t_{max}))$ where $d_{max} = d_{SD}$ and $t_{max} = 1$. T_{max} is the time within which the next-hop node has to be selected or a Path Error packet will be unicast to source. For better performance, the value of T_{max} is reduced linearly with increasing node density as with more candidates, there is higher probability of faster next-hop selection. T_{max} also increases discretely with increasing packet rate based on simulation results. The maximum value of T_{max} was calculated to be 0.1s based on the route lifetime based approach explained in [17].

4. PERFORMANCE EVALUATION

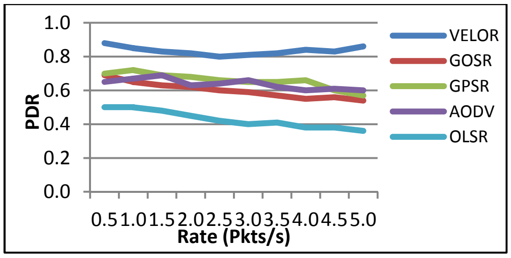
This section presents the results of the VELOR simulated performance using NS-2.35. The aim is to compare VELOR with four existing routing protocols, namely, GOSR, GPSR, AODV and OLSR. The evaluation metrics are packet delivery ratio (PDR), total number of data packets that reached the destination node over the total number of data packets that were transmitted from the source node, and average end-to-end delay (E2ED), average time taken in the delivery of data packets from the source to the destination.

4.1 Performance Evaluation of VELOR

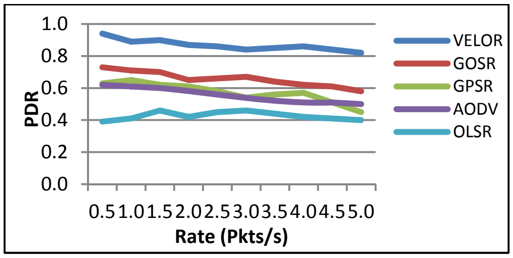
Table 1: Routing Protocol Simulation Parameters

Parameters	Values
Simulation Scenarios	Singapore
Simulation Area	2000m x 2000m
Number of CBR Sources	5 - 20
CBR Rate	0.5 - 5 packets/second
Data Packet Size	512 bytes
Simulation Time	300 seconds
Transmission Range	350m
MAC Protocol	IEEE 802.11

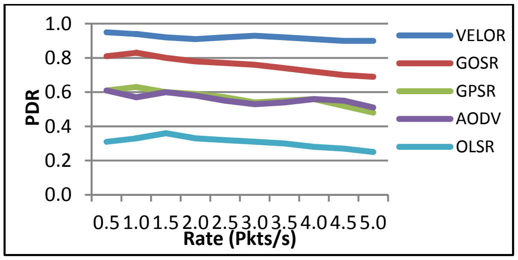
4.1.1 Average Packet Delivery Ratio



a) Results for 2000 nodes



b) Results for 2500 nodes



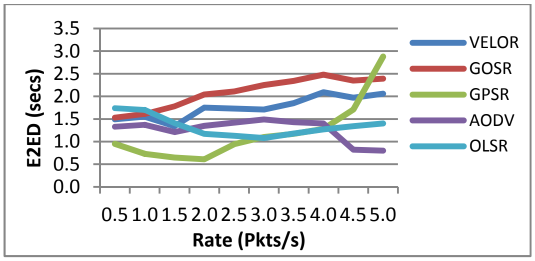
c) Results for 3000 nodes

Figure 1: Average Packet Delivery Ratio vs Packet Rate

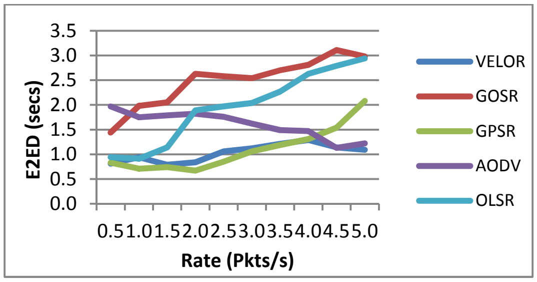
It can be observed that VELOR's performance is better than the other protocols, with as much as 35% improvement. A common observation is that the average packet delivery ratio decreases with an increase in the packet rate, but the decrease is marginal for VELOR, which shows that it can manage increased loads. Also, it can be seen form Figure 1(c) that VELOR has better performance in high density networks as during the next-hop node selection, it has a larger candidate group with potentially better candidates to choose from. Looking at the effect across network densities, it can be evidently seen that the average packet delivery ratio of protocols like VELOR and GOSR, which consider road topology, increases with increasing density. However, VELOR outperforms GOSR across all densities as it also considers mobility, to predict the future node location, apart from road topology.

4.1.2 Average End-to-end Delay

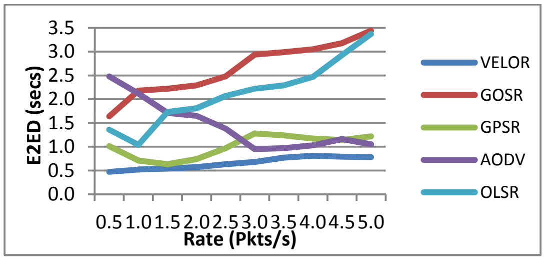
On the macroscopic perspective, an upward rise in the average end-to-end delay with increase in the packet rate is observed which can be attributed to the increase in network congestion. The reduced average end-to-end delay with increasing packet rate (increased congestion) in VELOR is because of the standby function which reduces signaling overhead significantly. AODV is the only protocol which has its average end-to-end delay decreasing with increase in the packet rate across all node densities as shown in Figure 2. A possible explanation for this could be the simplified forwarding employed by AODV where packets just store the destination address. This, coupled with the maintenance and frequent usage of only the best route, helps AODV perform better for higher packet rates.



a) Results for 2000 nodes



b) Results for 2500 nodes



c) Results for 3000 nodes

Figure 2: Average End-to-end Delay vs Packet Rate

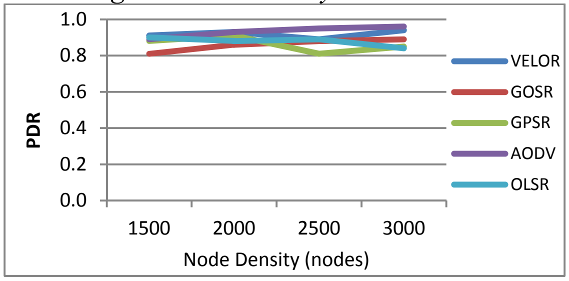
The average end-to-end delay of VELOR reduces significantly with an increase in the node density. This can be attributed to lesser path breakages which cause VELOR routes to remain in service for extended time-intervals, leading to lesser overhead signaling. Also, the standby interval is reduced as there is higher probability of finding a next-hop node; this leads to reduced end-to-end delay with increasing node density.

4.2 Performance EvaluatioMobility Models

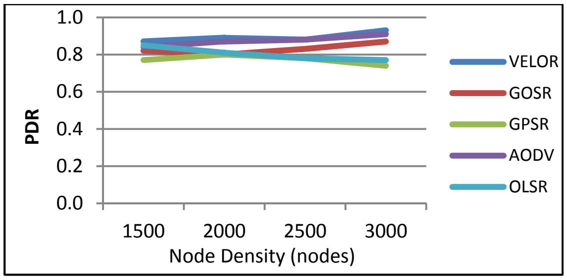
Table 2: Mobility Models Simulation Parameters

Parameters	**Values**
Simulation Scenarios	Random Waypoint, City Section, Manhattan, Singapore
Simulation Area	2000m x 2000m
Number of CBR Sources	5 - 20
CBR Rate	0.5 - 5 packets/second
Data Packet Size	512 bytes
Simulation Time	300 seconds
Transmission Range	350m
MAC Protocol	IEEE 802.11

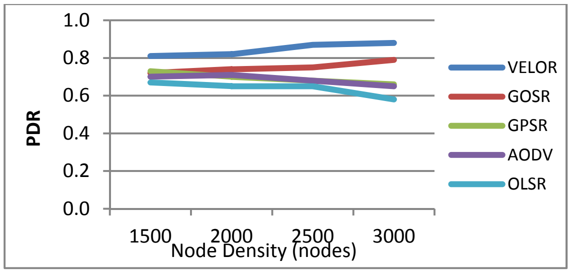
4.2.1 Average Packet Delivery Ratio



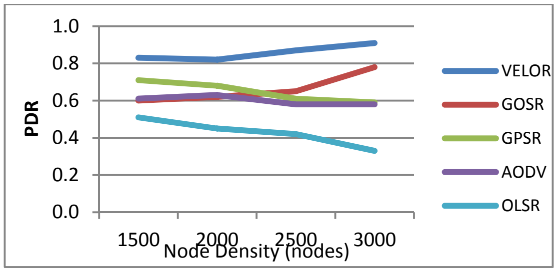
a) Results for Random Waypoint



b) Results for City Section



c) Results for Manhattan



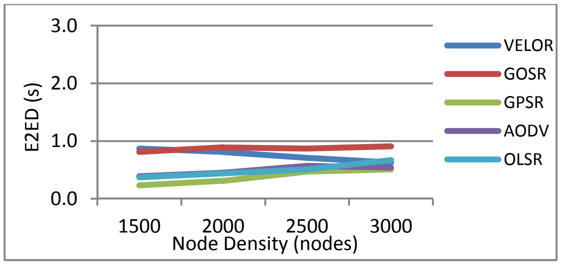
d) Results for Singapore

Figure 3: Average Packet Delivery Ratio vs Node Density

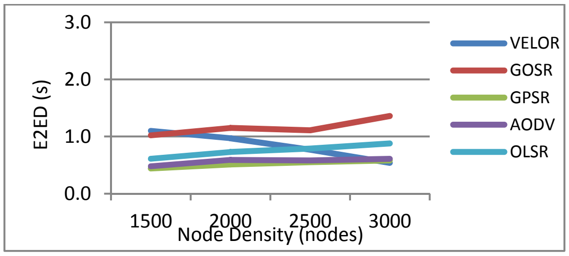
It can be observed from Figure 3 that as the node density is increased for all the models, the average packet delivery ratio slightly increases; but this only lasts till the node density reaches its critical value of around 2000. Following this as the node density increases further, it adds redundancy and thus degrades the protocols performance. The only exceptions to this rule are GOSR and VELOR. It can be seen in Figures 3(c) and 3(d) that the performance of GPSR and AODV drastically fall as the network gets more complicated in terms of road architecture and mobility parameters (as in Manhattan and Singapore model). In GPSR this is because of frequent switching to perimeter forwarding as greedy forwarding is ineffective. In Manhattan and Singapore scenarios, the performance of OLSR reduces steeply as higher control signaling is required for MPR assignment and maintenance of link state tables. Thus, comparison against various mobility models brings out the robustness of the routing protocols. VELOR and GOSR are the ones that can very well adapt to the changing scenarios, whereas the others, which solely make their forwarding decision based on shortest path algorithms, show degraded performance in realistic scenarios. The gap between VELOR and the other protocols widens as the complexity of the simulation scenario increases as shown in Figure 8.

4.2.2 Average End-to-end Delay

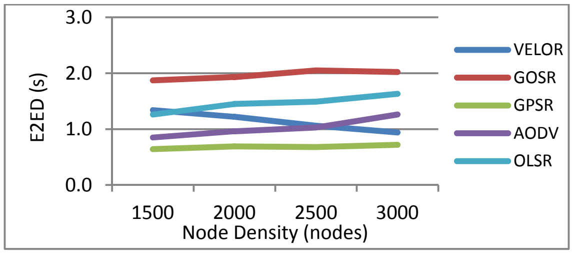
For simplistic mobility models, such as the Random Waypoint, all the other protocols, except GOSR, outperform VELOR, as seen in Figure 4(a), as a large amount of unnecessary computation is performed by VELOR. However, the average end-to-end delay for VELOR falls significantly when the node density increases as shown in Figure 4(d). This can be attributed to the standby function as the standby intervals become shorter due to the higher probability of finding the next-hop node faster. The standby interval is inversely proportional to the number of next-hop neighbor nodes. For OLSR, the MPR quality degrades with increasing network complexity and density. The signaling overhead and time taken to assign MPRs increase significantly with the increase in the number of level-1 and level-2 neighbor nodes. It can be observed that the average end-to-end delay for all other protocols, except for VELOR and GPSR, increases significantly with increase in network complexity. On one hand, VELOR has one of the highest delays for sparse networks simulated in simplistic scenarios whereas, in dense, urban networks simulated using realistic models, VELOR has one of the lowest delays.



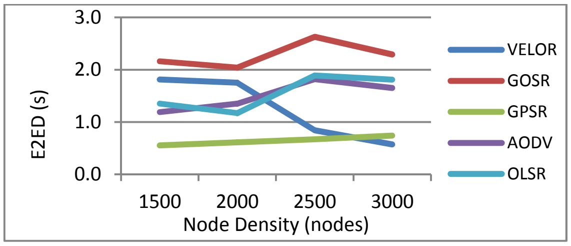
a) Results for Random Waypoint



b) Results for City Section



c) Results for Manhattan



d) Results for Singapore

Figure 4: Average End-to-end Delay vs Node Density

5. CONCLUSION

Reviewing the existing routing literature led to the identification of the strengths and weaknesses. Based on these findings, a velocity-based routing protocol, VELOR, was designed and implemented. The protocol first finds the intersections to be traversed along the routing path based on the road topology and vehicular traffic on each road segment. Selective flooding was designed and integrated to reduce congestion and signaling overhead. For inter-intersectional forwarding, the standby function was used for selecting next-hop node based on the parameters: farthest predicted neighbor and the transmission probability. In sparse networks, VELOR has a higher packet delivery ratio than the rest; however, it has a higher average end-to-end delay than all the other protocols except GOSR. Unlike the other protocols, VELOR's packet delivery ratio is not affected by change in scenario complexity and with increasing node density, the average end-to-end delay of VELOR decreases significantly across all scenarios.

6. ACKNOWLEDGEMENT

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