A GPSR Enhancement Mechanism for Routing in VANETs

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C. Bouras[1,2], V. Kapoulas[1,2], and E. Tsanai[2]

[1]Computer Technology Institute and Press "Diophantus", Patras, Greece
{bouras, kapoulas}@cti.gr,
[2]Computer Engineering and Informatics Dept., University of Patras, Patras, Greece
{bouras, kapoulas, tsanai}@ceid.upatras.gr

Abstract. Vehicular Ad Hoc Networks (VANETs) are considered as a special case of mobile Ad Hoc Networks (MANETs) and are recently gaining a great attention from the research community. The need for improved road safety, traffic efficiency and direct communication along with the great complexity in routing, makes VANETs a highly challenging field.. Routing in VANETs has to adapt to special characteristics such as high speed and road pattern movement as well as high linkage break probability. In this paper, we propose an enhancement mechanism for the GPSR routing protocol and present its performance for urban and highway scenarios. Its performance is compared to the performance of the most common MANET routing protocols adopted in VANETs. The proposed enhancement is shown to be beneficial in most occasions as it outperforms the rest of the tested routing protocols.

Keywords: VANETs, MANETs, Routing Protocols, Applications

1 Introduction

Vehicular Ad Hoc Networks (VANETs) are a special class of Mobile Ad Hoc Networks (MANETs) with unique characteristics. Similar to MANETs, VANETs are an autonomous and self-configured wireless network that allows communications without any dependency on infrastructures or a central coordinator. Any vehicle can be an active node in a VANET if equipped with wireless transceivers. Most nodes in a VANET are continuously moving with a wide range of speeds and directions in the same way as a vehicle moves in a roadway or an urban area. The moving rates in a VANET are in the general case higher than that in a typical MANET but more predictable for nodes traveling on the same direction. This means that nodes in a VANET, moving towards the same direction in a roadway maintain similar speeds and thus longer radio communication periods of time than those moving in opposite directions. Another unique characteristic of VANETs is their challenging surrounding environment that contains blocks of buildings, roadways that limit the possible node movements and roadside infrastructures that may provide internet access points along with a rich variety of services and applications.

The unique nature of VANETs provides some key advantages over MANETs but also introduces some challenging issues. A main advantage is the unlimited battery power of the vehicle when moving and the high energy levels that allow exceptionally high bandwidth links and integration with new technologies like LTE systems. However, a very important challenge in VANETs is the routing performance [1]. Importing existing MANET routing protocols directly into VANETs could lead to abyssal network performance and unsatisfactory performance. Compared to MANETs, the node movement in VANETs is more predictable allowing more effective position allocation algorithms and routing protocols that benefit from GPS and electronic maps. However, the node density may vary a lot due to traffic conditions. An important issue in the environment of VANETs is the presence of buildings in urban areas, which adds signal weakening and noise. Implementing a routing protocol able to select the best possible path which avoids passing through buildings and other obstacles in the topology is not an easy task.

Routing in VANETs has been an important field for research the last years. A lot of work exists that studies and analyzes routing in VANETs. In [2], [3] and [4] several routing protocols in MANETs and VANETs are being studied and categorized according to their routing strategy. A comparative performance analysis of AODV (Ad Hoc On-Demand Distance Vector), DSDV (Destination Sequenced Distance Vector) and DSR (Dynamic Source Routing) is conducted in [5] for rural and urban scenarios. In [6], general design ideas and components are being presented for reliable routing design and implementation and in [7], a quantitative model for evaluating routing protocols on highway scenarios is proposed. In [8], 3 realistic radio propagation models are presented that increase the simulation results' accuracy. A novel routing protocol for reliable vehicle to road-side AP connection is proposed in [9] that uses an algorithm for predicting the wireless links' lifetime. In [10], a road based VANET routing protocol is proposed that uses real-time vehicular traffic information to form the paths and is compared with existing well-known routing protocols. In [11], a cross-layer position based routing algorithm for VANETs is presented that performs better than the GPSR (Greedy Perimeter Stateless Routing) routing protocol. The algorithm, named CLWPR (Cross-Layer Weighted Position-based Routing), uses information about link layer quality and positioning from navigation.

The following of this work is organized as follows: Section 2 provides an overview of the communication types in VANETs and the most common routing protocols used in MANETs and VANETs that are the subject of study; Section 3 describes the proposed enhancement to the GPRS protocol (named GPRS-Modified or GPRS-M for short); Section 4 presents the reference scenarios and the simulations settings; Section 5 presents and discusses the results of the simulations and finally Section 6 gives the conclusions of this work along with ideas and directions for future work.

2 Routing in VANETs

A VANET is composed of static and mobile nodes, thus the common types of communication are:

- Vehicle to Vehicle (V2V)
- Vehicle to Infrastructure (V2I or I2V)
- Infrastructure to Infrastructure (I2I)

V2V is the direct communication between vehicles, which may occur in every topology as long as there is node movement inside the communication range. V2I is the communication between vehicles and infrastructures, which provide services related to safety, convenience, commercial purposes, internet access and others. I2I is the communication between infrastructures, which may be roadside units (RSUs), tool ways and others. Except from these 3 communication types, a mixed communication may occur, especially in cases of large inter-vehicle spacing and low traffic density. In such scenarios, infrastructures such as RSUs may forward the desired messages to the destination. Vehicles and infrastructures may all interact together and form WLAN, Ad Hoc or Hybrid Networks. The routing protocols that are being tested and evaluated in this work are presented below:

AODV. The Ad Hoc On-Demand Distance Vector [12] is intended for use by mobile nodes in an Ad Hoc network. It offers swift adaptation to dynamic link conditions, low processing and memory overhead, low network utilization, and determines unicast routes to destinations within the Ad Hoc network. It uses destination sequence numbers to ensure loop freedom at all times avoiding common problems associated with classical distance from vector protocols.

DSDV. Destination Sequenced Distance Vector routing [13] is adapted from the conventional Routing Information Protocol (RIP) to an Ad Hoc network routing. It adds a new attribute and sequence number to each route table entry of the conventional RIP. Using the newly added sequence number, the mobile nodes can distinguish stale route information from the new one, thus preventing the formation of routing loops.

DSR. Dynamic Source Routing [14] uses source routing, that is, the source indicates in a data packet's sequence of intermediate nodes the routing path. In DSR, the query packet copies in its header the IDs of the intermediate nodes that it has traversed into. The destination then retrieves the entire path from the query packet and uses it to respond to the source. As a result, the source can establish a path to the destination. If the destination is allowed to send multiple route replies, the source node may receive and store multiple routes from the destination. An alternative route can be used when some link in the current route breaks. In a network with low mobility, this is advantageous over AODV since the alternative route can be tried before DSR initiates another flood for route discovery.

OLSR. Optimized Link State Routing [15] operates as a table driven, proactive protocol, i.e., exchanges topology information with other nodes of the network regularly. Each node periodically constructs and maintains the set of neighbors that can be

reached in 1-hop and 2-hops. Based on this, the dedicated MPR algorithm minimizes the number of active relays needed to cover all 2-hops neighbors. Such relays are called Multi-Point Relays (MPR). A node forwards a packet if and only if it has been elected as MPR by the sender node. In order to construct and maintain its routing tables, OLSR periodically transmit link state information over the MPR backbone. Upon convergence, an active route is created at each node to reach any destination node in the network. The protocol is particularly suited for large and dense networks, as the optimization done using MPRs works well in this context. The larger and more dense a network is, the more optimization can be achieved.

GPSR. The Greedy Perimeter Stateless Routing [16] is based on positioning of the routers and assumes that every node has access to a location service and knows its position coordinates. GPSR makes greedy forwarding decisions using only information about a router's immediate neighbors in the network topology. The best next hop is considered the neighbor node with the least distance from the destination. When the greedy forwarding is impossible, the algorithm recovers by routing around the perimeter of the region.

3   Proposed GPSR Enhancement

The proposed GPSR enhancement is implemented in the NS-3 simulator and follows the implementation of [17]. Because of the intense and high speed mobility in VANETs, the GPSR forwarding process may not be always efficient. Choosing as next hop the neighbor node with the least distance from the destination may easily lead to recovery state as the link may brake due to opposite directions or great speed difference between the next hop and the destination. The proposed mechanism enhancement is applied on the greedy forwarding process during the best next hop calculation. The modified process handles not only the positions of the routers but also the speed, direction and link quality. The speed and direction is send as a velocity vector attached in the hello messages of the modified GPSR. The destination's position and velocity is added in the packet header in order to be available at the intermediate nodes. The position and velocity for every node is obtained from a location service that in the real world could be the GPS. For link quality assignment, every packet is tagged with an SNR value at the physical layer. This SNR packet tag is extracted at the routing layer during the hello messages receipt. The position, velocity and SNR information is stored in the neighbor table of every node and then is included in the next hop weight calculation.

Except from velocity and link quality, the enhancement mechanism also includes a future position prediction process (getFuturePos), a process for determining if nodes are moving in the same road and direction (inSameRD) and a next hop weight calculation process (CalculateW). The future position calculation uses the formula:

$$FutPos.x = Pos.x + Vel.x * dt(speed);$$
$$FutPos.y = Pos.y + Vel.y * dt(speed);$$

where dt() is a mapping function that returns the time from 1.0 up to 4.0 seconds based on the speed parameter. As the speed increases the returned time period decreases.

To examine if 2 nodes are moving in the same road and direction, the second process calculates the nodes' velocity vector angle, their line distance, and their dot product. If their velocity vectors are parallel and their line distance is less than the road width, the algorithm decides that they are moving in the same road. The overall process is presented in Fig. 1.
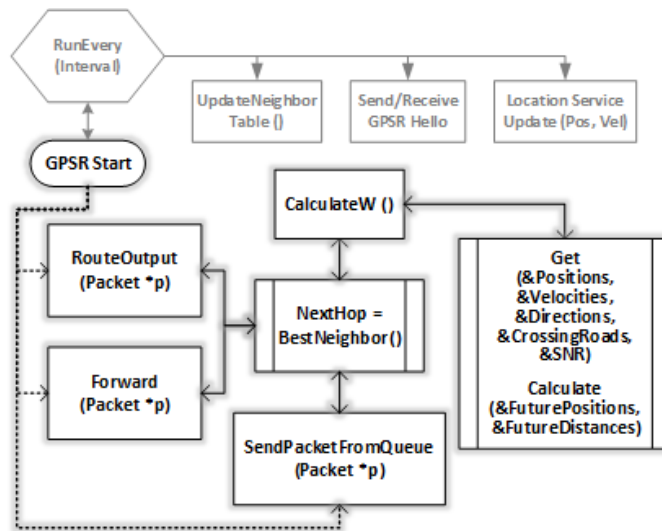

Fig. 1. Mechanism schema

When a need for packet transmission occurs, the Forward procedure of GPSR-M is called. At this point, the decision for the best next hop is made through the BestNeighbor procedure which triggers the CalculateW procedure.

```
1. Procedure Forward(packet)
2.    if neighborTable.isNeighbor(dst) then: nextHop ← dst;
3.    else nextHop ← neighborTable.BestNeighbor(myPos, myVel,
                                                dstPos, dstVel);
4.    if nextHop.addr->isValid() then: route->SetGateway(nextHop);
5.    else RecoveryMode(route);
6.    return;
7. EndProcedure
```

The BestNeighbor procedure iterates through the neighbor table of the index node and triggers the CalculateW for every neighbor in order to return the best next hop.

```
1. Procedure BestNeighbor(myPos, myVel, dstPos, dstVel)
2.    initialW ← CalculateW(myPos, myVel,..,dstPos, dstVel, snr);
3.    W ← CalculateW(myPos, myVel, nTable.Pos, nTable.Vel,
                     dstPos, dstVel, nTable.Snr);
4.    for i ← nTable.begin() to nTable.end():
5.      if W > CalculateW(myPos,myVel,i->pos,i->vel,dstPos,
                          dstVel, i->Snr) then:
6.        W ← CalculateW(myPos, myVel, i->pos, i->vel, dstPos,
                         dstVel, i->Snr);
7.        nextHop.addr ← i->addr;
8.    if initialW > W then: return nextHop;
9.    else return IpV4Address::GetZero();
10. EndProcedure
```

The CalculateW procedure is called for every neighbor node of the index node through the BestNeighbor procedure and returns the calculated weight of the examined node based on the input routing data. The 5 weight factors have been set after extended simulation tests for performance analysis of CalculateW.

```
1. Procedure CalculateW(srcPos,srcVel,indxPos,indxVel,dstPos,
                        dstVel,snr)
2.    W ← +INF, w1 ← 0.25, w2 ← 0.15, w3 ← 0.25, w4 ← 0.15, w5 ← 1;
3.    p1 ← getFuturePos(srcPos, srcVel);   //Source future pos
4.    p2 ← getFuturePos(indxPos, indxVel); //Index future pos
5.    p3 ← getFuturePos(dstPos, dstVel);   //Destination future pos
6.    d1 ← getDistance(p1, p2); //currently not used
7.    d2 ← getDistance(indxPos, dstPos);
8.    d3 ← getDistance(p2, p3);
9.    if inSameRD(indxPos, IndxVel, dstPos, dstVel) then: w2 ← 0;
10.   if inSameRD(indxPos, IndxVel, srcPos, srcVel) then: w4 ← 0;
11.   W ← (w1+w2)*d2 + (w3+w4)*d3 + w5*d3/(snr);
12.   return W;
13. EndProcedure
```

Two basic cases where the GPSR enhancement mechanism significantly improves the network performance are shown in Fig. 2. In the left case, the mechanism forms the green route and avoids the route change that will occur in the red route in a very short amount of time. In the right case, the default GPSR forwarding process chooses the red route and shortly will fall in recovery mode. The proposed mechanism avoids that. The improvement gets more intense as the number of the intermediate nodes rises. The code of the mechanism can be found in the web site: http://ru6.cti.gr/ru6.
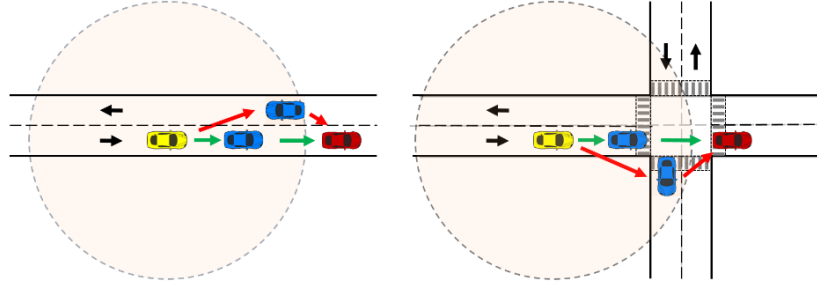
Fig. 2. Routing in a highway (left) and a junction (right). The red arrows represent the GPSR routes and the green the modified GPSR routes

4   Reference Scenarios

The evaluation of the routing protocols in VANETs is conducted for 2 topology scenarios. The first topology is an Urban Area and the second a highway. For both scenarios, the tools JOSM (https://josm.openstreetmap.de/), SUMO [18] and BonnMotion [19] were used for the network topology generation. The common network parameters that both scenarios share are shown in Table 1.

Table 1. Network parameters for both scenarios

Node Transmission Range	300m
Mac Layer	IEEE 802.11p Wave
PhyMode	Ofdm6mbs10MHz
Propagation Model	FriisPropagationLossModel
Packet Size	128 Bytes
Packet Interval	0.01s
Application	Udp Server-Client

4.1   Urban Area Scenario

In this scenario, the road network from the city of Athens is simulated, extending for about 2 x 2 km. The city simulation process includes fetching the city map including all the road elements (traffic lights, junctions, road directions, etc.) with the use of JOSM, preprocessing it with SUMO to generate vehicles and road traffic and then import them to NS-3. The number of nodes is 130 with their movement following random vehicle movements with respect to the imported road network. The nodes are never allowed to move outside the area limits keeping the node density stable. Roads leading outside the selected area are properly edited to lead back any vehicles approaching the limits. The maximum node speed is 85 km/h and the average 60 km/h. All nodes are equipped with Wi-Fi devices and transmission range up to 300m. The selected Mac layer is the IEEE 802.11p Wave with 6Mbps data rate and 10MHz channel bandwidth.

Except from vehicle nodes, the simulated area contains 2 Base Stations for V2I or I2I communications. During the simulation, all 3 types of VANET communications take place. The application used for packet transmission is the UDP Server-Client Application with 128 bytes packet size and 0.01s packet interval. The simulation time is 150s with a warm-up time of 30s. The number of flows in the network is 10 (7 V2V, 2 V2I, 1 I2I) and the minimum flow duration is 10s. The simulation is tested for the routing protocols OLSR, AODV, DSDV, DSR, GPSR and the proposed GPSR-M. The evaluation is based on packet delivery ratio, end to end delay and energy consumption (using the NS-3 WifiRadioEnergyModel). The scenario is presented in Fig. 3.

Fig. 3. The simulated Urban area scenario. On the left: The original area from the Open Street Map. On the right: The final road network to be tested.

4.2 Highway Scenario

The highway scenario simulates the case of high distance roadways with high vehicle movement speeds and course stability. In this scenario, the node's mobility route is more predictable and tends to keep its current state. Course changes take place mainly when a vehicle moves to another lane. In the tested scenario, 100 nodes are moving with average speeds varying from 20km/h up to 180km/h. The communication type is V2V with the source and destination node moving towards the same direction. The distance between them is 1 km and the nodes' transmission range is 300m. This scenario type is produced by a custom simple generator which can be found together with the simulation code. Fig. 4 depicts the described scenario.
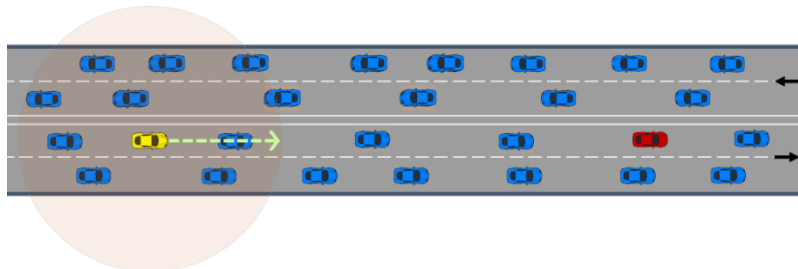

Fig. 4. Highway Scenario

5 Simulation Results

5.1 Urban Scenario Results

The results for the simulation of the urban scenario are presented below. Three metrics are presented: packet delivery ratio, end-to-end delay and energy consumption.

Fig. 5 shows the packet delivery ratio for each tested routing protocol. The AODV seems to be the worst performer while GPSR seems to be the best choice out of the existing protocols. This is expected as AODV (as a reactive routing protocol) is not very well suited for network with frequent topology changes (such as VANETs). OLSR and DSDV as pro-active routing protocols exhibit better performance in this case. DSR, although a reactive routing protocol, handles topology changes with less messages and adapts better that AODV bringing its performance in par with OLSR. GPSR, taking into account the position of the nodes has a much better performance. Still, the proposed enhancement improves the PDR from approximately 75% for GPSR up to approximately to 79%, which is a quite good enhancement. This is due to moving nature of the nodes in a VANET which constantly changes the position of the nodes. Thus the information GPRS uses can quickly get a bit outdated. The proposed enhancement anticipates this change and estimates a better position for the nodes at the time they are used to relay a message.

Fig. 6 shows the (average) end-to-end delay achieved for each routing protocol tested. AODV is again the worst performer, but OLSR is the best choice for keeping end-to-end delay at a minimum level. GPSR is behind OLSR and DSR. This can be explained by the fact that the position information is getting slightly outdated by the time a node is used (and some time has passed from when its position was acquired). The change is small enough to not disrupt the network and sustain a high PDR (as discussed previously) but seems to be large enough to result in less efficient routes. However with the proposed enhancement applied, it overtakes DSR and moves in second place close to OLSR. The reduction of the end-to-end delay with the application of the proposed enhancement is quite impressive (the end-to-end delay drops to less than half), and is attributed to the better estimation of the then current position of each node.

Fig. 7 shows the total energy consumption for each routing protocol tested. AODV is again the worst performer and must clearly be avoided for VANETs in such urban settings. This is probably due to the frequent topology changes that result in disconnected paths and the need to frequently re-run the route discovery. DSR uses the less energy with all the other protocols following using approximately the same energy. The proactive routing protocols manage to keep the energy consumption at this lower level as they update the routes regularly to avoid disconnections. DSR manages to use slightly less energy as it does not rediscover the route globally but somehow tries to re-route locally, and this proves more than enough. The proposed enhancement shows a very small reduction but no clear improvement. However, its application does not increase the energy consumption footprint of GPSR. This means that the proposed enhancement can be applied without any energy consumption drawbacks.
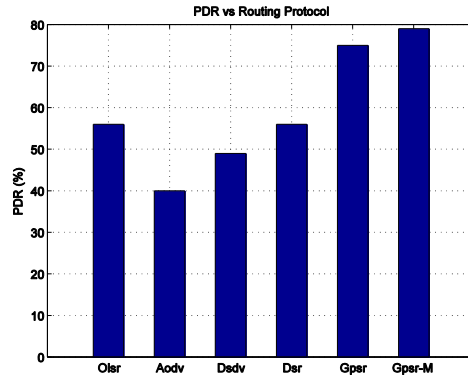
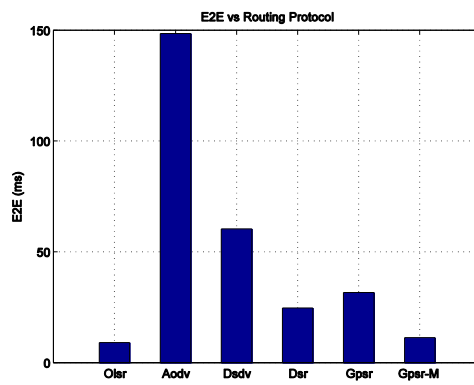**Fig. 5.** Packet Delivery ratio VS Routing Protocol

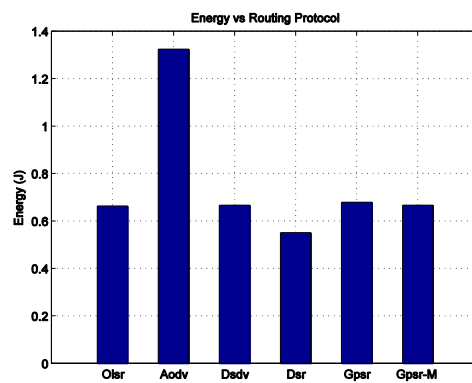**Fig. 6.** End to End Delay VS Routing Protocol

Fig. 7. Total Energy consumption VS Routing Protocol

Looking at the combined results, GPSR with the proposed enhancement is a quite good choice for VANETs in such urban settings. The small deficits (with respect to DSR) for the end-to-end delay and the energy consumption are a small compromise for the increased packet delivery ratio. In cases where GPSR is used, the proposed enhancement either improves (even slightly) all of these metrics and therefore is a really nice contender to be applied.

5.2   Highway Scenario Results

The results for the simulation of the highway scenario are presented below. The same three metrics (packet delivery ratio, end-to-end delay and energy consumption) are presented. However this time they are shown against the average vehicle speed.

Fig. 8 shows the packet delivery ratio for the tested routing protocols against the average vehicle speed. DSDV is the worst performer followed by AODV and OLSR, which seem to drop to very low level of PDR as the average vehicle speed increases. DSR displays an "erratic" behavior with large fluctuation in the PDR for different average vehicle speeds. This is due to the more frequent topology changes that result from the higher speeds. Clearly, these routing protocols are not suitable for such scenarios. GPSR has better PDR but this seems to drop as the average vehicle speed increases. This is explained as the higher speeds result in higher deviation of the actual position of a node from the reported position of that node when it was queried. The higher the speed the higher the variation, the lower the performance as nodes considered neighboring can actually be out of reach. GPSR with the proposed enhancement is clearly the best performer. The enhancement seems to improve GPSR quite a lot for such scenarios and improve the PDR above 90% in most cases. This is due to fact that this routing protocol takes the speed into account and estimates correctly the actual position of the nodes at each time (as opposed to the reported one). An important consequence of this is that it maintains this high level of PDR for high vehicle speeds, with no indication that higher speeds will present any problem; i.e., it scales very well with the vehicle speeds.

Fig. 9 shows the average end to end delay for the tested routing protocols against the average vehicle speed. The results indicate that OLSR maintains steady levels of delay up to 20 ms for speeds up to 100 km/h. DSDV follows the OLSR and shows lower levels of delay than DSR and AODV for speeds up to 60 km/h. The GPSR shows intense reduction of delay for speeds greater than 60 km/h and performs better than the previously mentioned protocols for high speeds. From this speed onwards, it seems that the error in the node position can be quite high as to result in disconnections (and the lower PDR seen above); however when there is no disconnection the route is good enough to result in low end-to-end delay. The enhanced GPSR mechanism seems to improve significantly the end to end delay of GPSR and performs better for almost all the tested speeds. As explained above this is due to the fact the enhanced protocol does not suffer from a bad knowledge of the actual position of nodes.
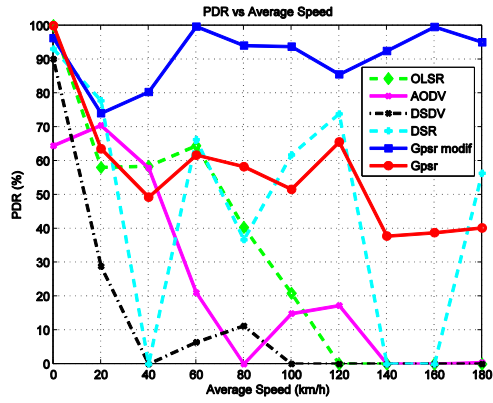
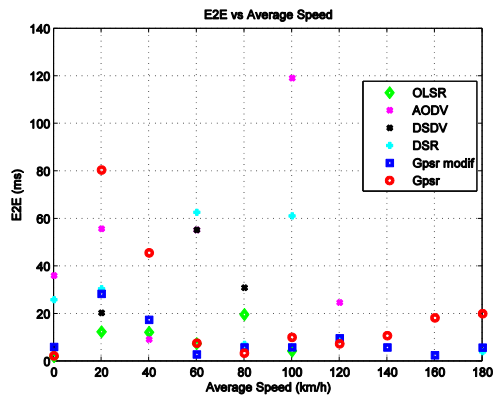**Fig. 8.** Packet Delivery ratio VS Average Speed

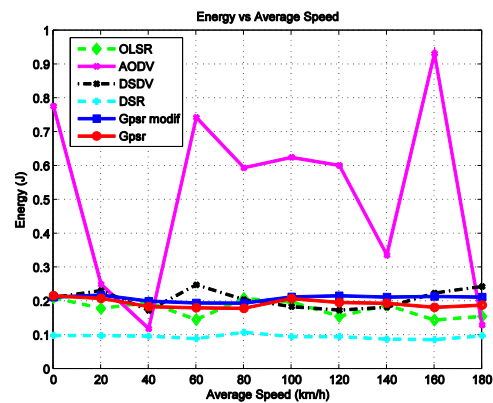**Fig. 9.** End to End Delay VS Average Speed

Fig. 10. Total Energy consumption VS Average Speed

Fig. 10 shows the energy consumption for the tested routing protocols against the average vehicle speed. AODV seems to be the most energy hungry protocol, while DSR is the best performer. All the other protocols are close together. GPSR with the proposed enhancement use slightly more energy than GPSR but the increase is quite low. This is more-or-less the same picture as with the urban scenario.

The combined results demonstrate that GPSR with the proposed enhancement is a quite good choice for VANETs in such highway settings. Again, the small deficits for the end-to-end delay and the energy consumption are a small compromise for the increased packet delivery ratio.

The proposed enhancement improves the PDR of GPSR in all cases and improves the end-to-end delay and energy consumption of GPSR in several cases. In the rest of the cases, the deficit is quite small and tolerable for obtaining the higher PDR.

Therefore, the proposed enhancement is a strong contender to be implemented together with GPSR.

6 Conclusions and Future Work

In this work, we present an enhancement for the GPSR routing protocol that makes use of location and direction information as well as link quality metrics to produce routes that improve the performance of the network. The enhanced protocol is tested (with simulations) against several other routing protocols.

The proposed enhancement is shown to achieve higher packet delivery ratio for the network, a low end-to-end delay (but not the lowest), while keeping the energy consumption at the same low levels (again not the lowest) of GPSR. However, overall is shown to be the best choice as the small deficits in end-to-end delay and energy consumption are quite small compared to the achieved improvement in the packet delivery ratio.

Our plan for future work includes the improvement of the weight calculation algorithm by implementing a more accurate positioning and direction model. This will be achieved by extending the existing location service model and introducing road models from existing city maps. This extension will improve the accuracy of the algorithm for weather two vehicles are moving in the same road and direction. In addition, our future work includes the testing of our mechanism in scenarios with building propagation models and the adaptation of the mechanism in such scenarios. The final goal will be the routing orientation to be also based on environment obstacles and noise.

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