Performance Evaluation of Routing Mechanisms for VANETs in Urban Areas

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Abstract. Mobile Ad hoc Networks (MANETs) and especially Vehicular Ad hoc Networks (VANETs) have recently gained large interest and their performance is heavily studied. A great challenge in VANETs, especially in an urban setting, is the routing scheme used and the subsequent performance obtained. This work presents an experimental performance evaluation of routing mechanisms in VANETs, using simulation, within an urban Manhattan grid like environment. It also describes and evaluates an enhancement of the Greedy Perimeter Stateless Routing (GPSR) protocol that takes into account the motion of the vehicles and the nature of the urban environment. The simulation results demonstrate that the proposed enhancement to the GPSR protocol manages to significantly increase the delivery ratio without increasing the power consumption; nevertheless, in some cases the improvement on delivery ratio is achieved at the expense of slightly increased end-to-end delay.

Keywords: Ad-hoc networks · MANETs · VANETs · Routing protocols

1 Introduction

Vehicular Ad hoc Networks (VANETs) represent 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. The moving rates in a VANET are generally 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 connectivity periods 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 access points to the internet along with a rich variety of services and applications.

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A great challenge in VANETs is the routing performance [16]. Importing existing MANET routing protocols directly into VANETs may lead to unsatisfactory network performance. Compared to MANETs, the node movement in VANETs is more predictable allowing more effective position allocation algorithms and routing protocols that benefit from the availability of the Global Positioning System (GPS) and electronic maps. However, node density may vary a lot due to traffic conditions. An important issue in the environment of VANETs is the presence of buildings in rural 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 of research the last years. Numerous works exist which study and analyze routing in VANETs. In [9,13,15] several routing protocols in MANETs and VANETs are being studied and categorized according to their routing strategy. A comparative performance analysis of the Ad Hoc On-Demand Distance Vector (AODV), Destination Sequenced Distance Vector (DSDV) and Dynamic Source Routing (DSR) protocols is conducted in [1] for rural and urban scenarios. In [12], general design ideas and components are being presented for reliable routing design and implementation and in [8], a quantitative model for evaluating routing protocols on highway scenarios is proposed. In [17], three realistic radio propagation models are presented that increase the simulation results accuracy.

A novel routing protocol for reliable vehicle to roadside Access Point (AP) connection is proposed in [21] that uses an algorithm for predicting the wireless links' lifetime. In [18], a road based VANET routing protocol is proposed that uses real-time vehicular traffic information to form the paths and is compared against existing well-known routing protocols. In [11], a cross-layer position based routing algorithm for VANETs is presented that performs better than the Greedy Perimeter Stateless Routing (GPSR) protocol. The algorithm, named Cross-Layer, Weighted, Position-based Routing (CLWPR), uses information about link layer quality and positioning from navigation.

In this paper we conduct an experimental performance evaluation of efficient routing mechanisms in MANETs, using simulation, for the case of VANETs within an urban environment (modeled by Manhattan grid). We also propose an enhancement of the GPRS protocol that takes into account the motion of the vehicle to estimate their position at future times, as well as the nature of the urban environment (i.e. the grid, in order to favor vehicles at crossroads as the intermediary nodes). The study compares Ad Hoc On-Demand Distance Vector (AODV), Destination Sequenced Distance Vector (DSDV), Dynamic Source Routing (DSR), Optimized Link State Routing (OLSR), Greedy Perimeter Stateless Routing (GPSR) and the above proposed modification of the GPSR, and measures the packet delivery ratio, the end to end delay and the power consumption for each routing protocol in various scenarios. The results show that the proposed enhancement to the GPSR protocol outperforms all the other protocols in all cases.

The remainder of the paper is organized as follows: Sect. 2 provides an overview of the routing protocols used in MANETs and VANETs that are the subject of study, and describes the challenges associated with VANETs in an urban setting; Sect. 3 describes the proposed enhancement to the GPRS protocol (named GPRS-Modified of GPRS-M for short); Sect. 4 presents the simulation setting and the reference scenario; Sect. 5 presents and discusses simulation results; and finally Sect. 6 presents our conclusions and ideas for future work.

2 Overview of Routing in MANETs and VANETs

2.1 Routing Protocols

The routing protocols compared in this paper are briefly introduced below. The GPSR protocol is presented in more detail to ease the understanding of the proposed enchancement in Sect. 3.

AODV. The Ad Hoc On-Demand Distance Vector [19] routing 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 [5] 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 [7] uses source routing, that is, the source indicates in a data packets sequence of intermediate nodes on the routing path. In DSR, the query packet stores within its header the IDs of the so far traversed intermediate nodes. 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 [6] 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, the more optimization can be achieved compared to the classic link state algorithm.

GPSR. The Greedy Perimeter Stateless Routing [10] is based on positioning of the routers and assumes that every node has access to a location service and knows its position coordinates. It also assumes that the source node is aware of the final destination nodes location. The GPSR allows routers to be nearly stateless, and requires propagation of topology information for only 1 hop. This means that each node need only to store information about its neighbors positions. The aim of GPSR is to take advantage of geographys properties in routing and allow high performance in forwarding without using other information. The GPSR operates in two modes based on the position of the index node, the neighbors and the final destination.

The first mode, the "greedy mode", is the main strategy of forwarding packets through intermediate nodes that are considered as best next hops. As best next hop is considered the neighbor node with the least distance from the destination. Packets are directly forwarded to this neighbors and form a short path to the destination based on positioning. The operation of this mode is illustrated in the left part of Fig. 1. Although this is the main state of the GPSR, there are cases where the density and the positioning of the nodes is such that does not allow forwarding using this approach.

When the greedy forwarding is impossible, the algorithm recovers by routing around the perimeter of the region. This is the second forwarding mode or else the "recovery/perimeter mode". When entering this mode, packets are marked for their new state and are forwarded according to the counterclockwise rule in relation to the source–destination line; i.e., neighboring nodes are tried as next hops, in the order they are encountered when starting from the source–destination line and turning around counterclockwise. The operation of this mode is illustrated in the right part of Fig. 1 and goes on until a node closer to the final destination than the recovery entry node is found. In the right part of Fig. 1 the orange node is the recovery entry node that informs the source node S about not having a neighbor with less distance to the destination D than itself.

2.2 Challenges

In an urban setting the presence of buildings in the area of the network topology plays a crucial role on the packet delivery success rate and adds a great complexity and challenge on the routing level. Buildings affect radio transmission

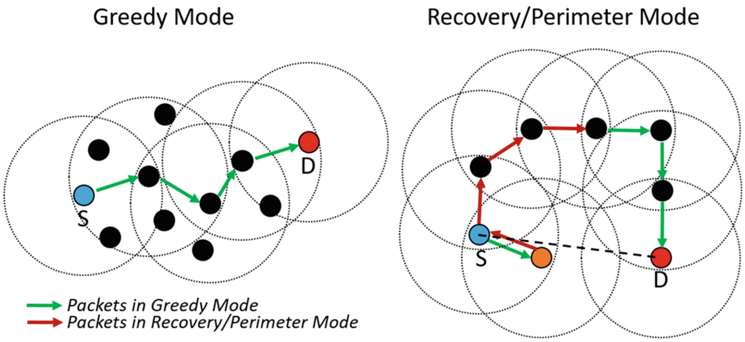


Fig. 1. The Greedy and the Recovery/Perimeter modes of the Greedy Perimeter Stateless Routing.

and restrict the communication between the nodes of the VANET. The fact that communication in VANETs takes place in the high frequency of 5GHz (which is more-or-less the standard frequency used in VANETs) makes the communication in areas with buildings even harder. These difficulties arise from penetration through buildings, reflections, refractions, diffractions, etc. At the same time the relatively high speed of the nodes, the resulted increased mobility and the frequent topology changes add additional challenge to the problem of establishing routes between the nodes of the VANET. Multi-hop communication and route maintenance in these scenarios are very challenging as links can be established only when the nodes are within line of sight (LOS) or slightly out of LOS (e.g., just behind corners and close to road intersections) and possibly for a relatively small time period as the involved vehicles may move in different directions.

As a result, the existing routing protocols are not expected to perform satisfactorily; indeed, as shown in Sect. 5, their performance is rather poor. This highlights the need to come up with solutions that take into account the urban setting and design routing protocols that a are more suitable for it. In this direction the proposed enhancement (described in the following section) takes into account the nodes motion information to better estimate their position at each time, and also identifies that the crossroads are the places where nodes can be better intermediates. Thus, it tries to select as next hop a node that, at the time of the transmission, is estimated to be at a crossroad (i.e., the best intermediate).

3 Proposed Enhancement to GPSR

3.1 Overview of the Proposed Enhancement

The challenge for GPSR is to avoid as much as possible any route dead ends and recovery mode entries. Our proposed implementation for propagation in an area with buildings is based on a previous approach for optimization on highways and areas without obstacles. In the previous approach [3], the GPSR routing protocol was enhanced in order to estimate future positions of nodes (using their speed and direction information) and hence select intermediate nodes that maintain higher route lifetimes and avoid link breakages while transiting data packets.

In an open field, without taking into account the building obstacles, the mechanism of [3] can perform at relatively high levels without the need for further major modifications. However, in the case of an urban environment case, the GPSR protocol with this additional mechanism can easily fall into recovery mode and fail to reach the destination with the greedy algorithm in the first place. Figure 2, shows two common cases where the original and the modified GPSR greedy algorithm of [3] cannot avoid falling into recovery mode. In order to solve this, the weight parameters of the proposed mechanism have to be changed.

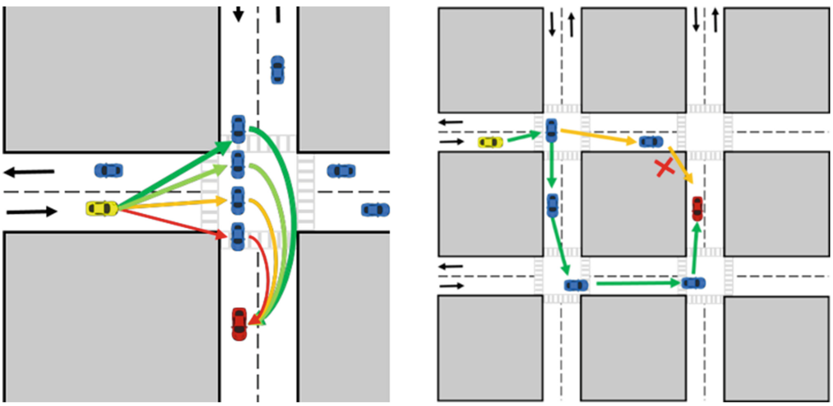


Fig. 2. Two common cases where the GPSR greedy algorithm falls in recovery mode. Left: The routes are chosen in an order from red to green as the vehicles, in the vertical road, move and successively fall out of reach. Right: The yellow route is chosen as first optimal path but fails to reach the destination. The green route is formed in recovery mode (Color figure online).

A key factor for multi-hop communications in a Manhattan-like grid with buildings seems to be any node located inside or very close to road intersections. Road intersections can function as joints for multi hop routes that do not follow a straight line. Figure 3, illustrates such a case.

In the new extension of the GPSR routing protocol, the neighbor nodes that are predicted to be located for the longest time period on a road intersection (and thus in the LOS with the index node), will be assigned less weight among the other neighbors. The new proposed weighting algorithm assigns higher priority to neighbor nodes moving towards the destination and those that are going to be longer inside the next road intersection in the same time. With this approach, the probability of keeping a route up is higher as intersections provide direct visibility with nodes on more directions.

Fig. 3. Multi-hop route from source (yellow node) to destination (red node). Nodes moving in road intersections function as route connectors (Color figure online).

Figure 4, shows the formation of 3 routes while utilizing the GPSR routing. The red route depicts the case of not including buildings on the propagation. As expected, the signal cannot reach the next desired hop by penetrating the building. The yellow one is the case of forming a route while utilizing the default (and first proposed mechanism) GPSR routing. As the algorithm is greedy and based only on current and predicted future positions, it eventually reaches a dead end. The green route, which is formed when using the new proposed mechanism and giving priority on nodes located in intersections, manages to reach the destination (red node) without falling on recovery mode.

3.2 Algorithm and Architecture

Figure 5 presents a simplified overview of the architecture of the GPSR routing protocol with the enhanced methods and sub procedures. The top procedures (grey color) run periodically according to the hello interval initialization. The remainder procedures run on demand, when a packet transmission is required.

The proposed extensions and modifications include:

- GPSR hello packet header: Addition of a vector velocity field that is going to be used for position prediction and direction determination for every neighbor node.
- SNR Tag. Addition of a piggy back field to hello messages for the SNR value from the MAC layer during packet receipt. This field may be used while storing neighbors to the index neighbor table.
- Modifications and additions on the presented procedures in Fig. 4:

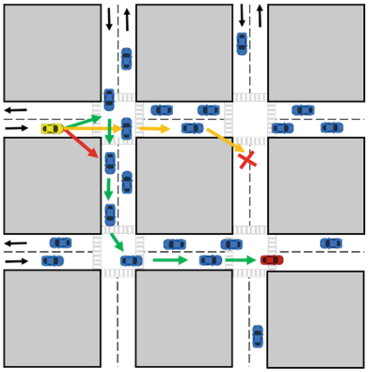


Fig. 4. Multi-hop route from sender (yellow node) to destination (red node). Yellow route: Default GPSR routing. Red route: The route without the buildings propagation model. Green route: The GPSR route formation with the new proposed extension for scenarios with buildings (Color figure online).

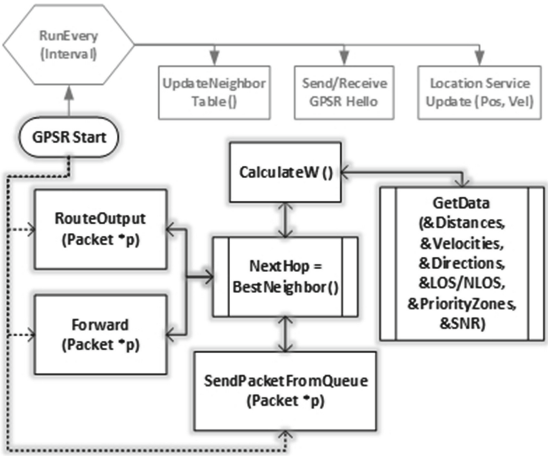


Fig. 5. Enhanced GPSR architecture.

1. RouteOutput(): Calls the modified BestNeighbor()
2. Forward(): Calls the modified BestNeighbor()
3. SendPacketFromQueue(): Calls the modified BestNeighbor()
4. BestNeighbor(): Uses the modified CalculateW()
5. CalculateW(): The weight calculation process for the next hop
6. GetData(): This sub process is in fact a simplified set of implemented methods that calculate specific parameters

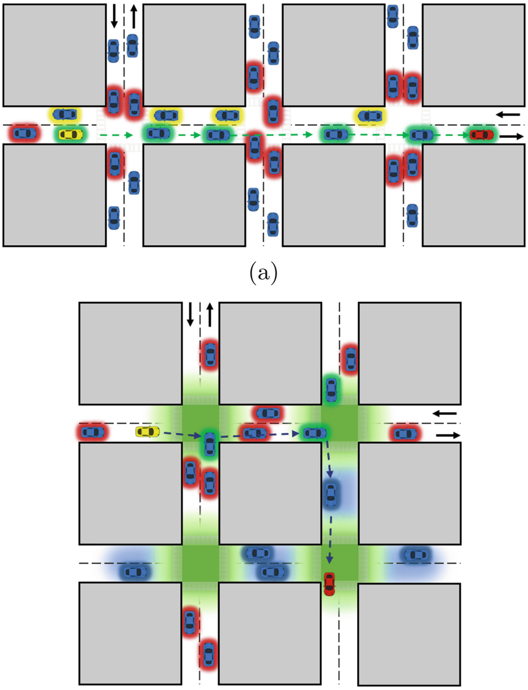
The main procedures of the proposed mechanism are the BestNeighbor and CalculateW and are executed every time a node executes the RouteOutput, Forward or SendPacketFromQueue.

The BestNeighbor procedure iterates through all the stored nodes in the neighbour table of the index node and executes the CalculateW for each of them. After the weight of each neighbour node has been calculated, the procedure compares the weight of the index node with the smallest weight found in the neighbour table. If a node in the neighbour table has a smaller weight than the index node, then it is defined as the best neighbour and eventually as the next hop. In the opposite case, the procedure returns a null IP address to the caller function and eventually the GPSR enters the recovery mode. This procedure is presented in Algorithm 1.

Algorithm 1. Procedure BestNeighbor

```
procedure BestNeighbor(myPos, myVel, dstPos, dstVel)
    initialW = calculateW (myPos, myVel, -, -, dstPos, dstVel);
    W = calculateW (myPos, myVel, neighborTable.begin()→Pos,
                    neighborTable.begin()→Vel, dstPos, dstVel);
    for (i = neighborTable.begin(); i != neighborTable.end(); i++) do
        if (W > calculateW (myPos, myVel, i→pos, i→vel, dstPos, dstVel)) then
            W = calculateW(myPos, myVel, i→pos, i→vel, dstPos, dstVel);
            nextHop.addr = i→addr;
        end if
        if (initialW > W) then
            return nextHop;
        else
            return IpV4Address::GetZero();
        end if
    end for
end procedure
```

The CalculateW procedure is invoked 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 CalculateW contains 2 modes based on the LOS and NLOS situation between the source and the final destination. The first mode is triggered when the source and destination node are within Line Of Sight and the second when they are not. For each case, a different calculation method of W is followed. In the first mode, the algorithm prioritizes neighbour nodes moving in similar way (same road and direction) with the source and destination and maintaining short future distances with the destination. The second mode, recognises 3 priority zones where zone 1 has the least weight and zone 3 the most. Zone1 covers areas in road intersections while zone 2 covers the areas that are in LOS with the destination. Finally, Zone 3 covers the remaining areas that have the least priority. See Fig. 6 for an explanation of the two modes of the CalculateW procedure.



(a)

(b)

Fig. 6. Modes in CalculateW. (a): LOS – greatest priority (Green), medium priority (Yellow), least priority (Red). (b): NLOS – Priority zone 1 with gradual weight (Green), zone 2 (Blue), zone 3 (Red) (Color figure online).

CalculateW uses specific routing data in order to proceed with the weight calculations. This data is received from the procedure GetData and is mostly related to current and future node positions, velocities and directions. In addition, several auxiliary procedures define whether a node is located in an intersection and whether it is within LOS with another node. Some of these auxiliary methods are the inIntersectionTime, inLos, inLosTime, getDirections and dt. All these auxiliary procedures are called directly or indirectly form CalculateW. The pseudocode of CalculateW procedure is presented in Algorithm 2.

The required location data for the calculation of W is provided by the auxiliary GetData sub procedure which is in Algorithm 3.

The previously described procedures are called when a need for packet transmission occurs. Algorithm 4 presents the forward procedure of the GPSR that calls the previously described BestNeighbor and its modified sub procedures.

The described mechanism and the integration with the GPSR routing protocol have been implemented in the NS-3 simulator. The full source code with the implementation of the proposed routing mechanism, the propagation model used in this work and its Pyviz extensions for NS-3 can be found in http://ru6.cti.gr/ru6/research-areas/network-simulations.

Algorithm 2. Procedure CalculateW

```
procedure CALCULATEW(IndxPos, IndxVel, DstPos, DstVel, SrcPos, SrcVel)
    GetData ();
    W = +∞;
    if (inLoS (SrcPos, DstPos)) then ▷ /* Mode 1: Source &destination in LOS */
        double w1 = 0.25, w2 = 0.1;
        if (inLoS (IndxFutPos, DstFutPos)) then
            if (getDirection (IndxVel) == getDirection (DstVel)) then
                w1 = 0.0;
            else
                w1 = 0.75;
            end if
        end if
        if (inLoS (IndxFutPos, SrcFutPos)) then
            if (getDirection (IndxVel) == getDirection (SrcVel)) then
                w2 = 0.0;
            else
                w2 = 0.01;
            end if
        end if
        W = Node_DestFutDist*(1+ w1 + w2);
    else                        ▷ /* Mode 2: Source & destination in NLOS */
        w1 = 0.5, w2 = 2; InterSectionT = 0.0;
        if (inIntersection(IndxPos, IndxVel) && ((Indx_DestFutDist -
0.25*Src_DstFutDist) < Src_DstFutDist)) then                ▷ /* Zone 1 */
            InterSectionT = inIntersectionTime (IndxPos, IndxVel);
            W = Indx_DestFutDist*(1-w1-InterSectionT/100 );
        else
            if ((((Indx_DestFutDist - 0.25*Src_DstFutDist) < Src_DstFutDist) &&
(inLoS (IndxFutPos, DstFut-Pos))) || (((Indx_DestCurDist - 0.25*Src_DstCurDist)
< Src_DstCurDist) && (inLoS (IndxPos, DstPos)))) then       ▷ /* Zone 2 */
                W = Indx_DestFutDist + w2*Indx_SrcFutDist;
            else                                            ▷ /* Zone 3 */
                W = 2*Indx_DestFutDist + w2*Indx_SrcFutDist;
            end if
        end if
    end if
    return W;
end procedure
```

4 Simulation Settings

4.1 Reference Scenario

In this work, the studied topology is a Manhattan grid area with blocks of buildings and all simulations are conducted in the network simulator NS-3. Compared to scenarios in open space (i.e., without buildings), this scenario's propagation

Algorithm 3. Procedure GetData

```
procedure GetData
    SrcSpeed = sqrt(pow(SrcVel.x, 2.0) + pow(SrcVel.y, 2.0));
    IndxSpeed = sqrt(pow(IndxVel.x, 2.0) + pow(IndxVel.y, 2.0));
    DstSpeed = sqrt(pow(DstVel.x, 2.0) + pow(DstVel.y, 2.0));
    SrcFutPos.x = SrcPos.x + SrcVel.x * dt(SrcSpeed);
    SrcFutPos.y = SrcPos.y + SrcVel.y * dt(SrcSpeed);
    IndxFutPos.x = IndxPos.x + IndxVel.x * dt(IndxSpeed);
    IndxFutPos.y = IndxPos.y + IndxVel.y * dt(IndxSpeed);
    DstFutPos.x = DstPos.x + DstVel.x * dt(DstSpeed);
    DstFutPos.y = DstPos.y + DstVel.y * dt(DstSpeed);
    Src_DstCurDist = GetDistance (SrcPos, DstPos);
    Src_DstFutDist = GetDistance (SrcFutPos, DstFutPos);
    Indx_SrcFutDist = GetDistance (IndxFutPos, SrcFutPos);
    Indx_DestCurDist = GetDistance (IndxPos, DstPos);
    Indx_DestFutDist = GetDistance (IndxFutPos, DstFutPos);
end procedure
```

Algorithm 4. Procedure forward

```
procedure forward(packet)
    myPos = locationService→GetPos(indx);
    myVel = locationService→GetVel(indx);
    dst = packet→GetDst();
    dstPos = packet→GetDstPos();
    dstVel = packet→GetDstVel();
    /* Get the best next hop */
    if (neighborTable.isNeighbor(dst)) then
        nextHop = dst;
    else
        nextHop= neighborTable.BestNeighbor(myPos, myVel, dstPos, dstVel);
    end if
    if (nextHop.addr→isValid()) then
        route→SetGateway(nextHop);
        return;
    else
        RecoveryMode(route);
        return;
    end if
end procedure
```

model computes the effects of the buildings presence to the signal path loss in street canyons.

In particular, the B1 – Urban micro-cell scenario of the WINNER II Channel Models [14] is used in our tests. As described in [14], all antennas are below the height of surrounding buildings and both Line Of Sight (LOS) and Not Line Of Sight (NLOS) cases are modeled. The signal reaches the receiver nodes as a result of the propagation around corners, through buildings, and between them.

The path loss calculations of the B1 Winner Model in LOS and in NLOS can be found in the summary table of the path-loss models, in [14].

Figure 7, shows the simulated network graph for 200 wireless ad hoc nodes in NS-3 for the cases where buildings are absent or present in the scenario. As seen, in the case without buildings, the resulting graph has a very large number of links (the relevant part of the figure is difficult to see because of the number of links) and it is very strongly connected. In the case with the buildings, the resulting graph has a greatly reduced number of links and this already indicates that the expected performance of the routing protocols will be much different.

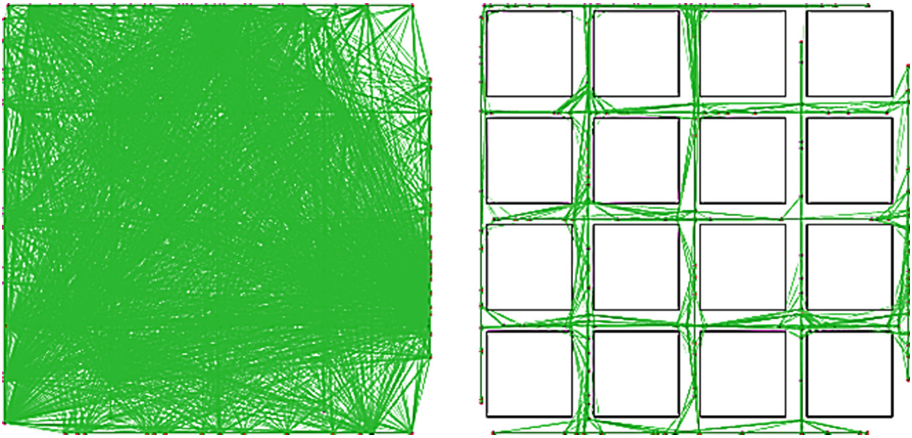


Fig. 7. Network graph for 200 nodes. Left: No buildings are modeled in propagation. Right: buildings are modeled with the 1 Winner Model.

4.2 Experiments and Parameters

For the evaluation of the studied routing protocols of this work as well as the proposed GPSR routing protocol with the integration of the previously presented mechanism, 2 set of simulations are conducted in the reference scenario. Each set is conducted for 3 scenario settings. For each scenario setting, each set of simulation is conducted for 5 different random node placements and mobility. For the node mobility generation the BonnMotion [2] software is used. All the network parameters and the scenario setting are presented in Table 1. Please note, that the density of the nodes is kept almost invariant, as the number of nodes increases with the size of the grid.

The first set of simulations is conducted to evaluate the performance of the studied and proposed routing protocols in the case of LOS between sender and final receiver. In this set, during the whole transmission, the sender and receiver maintain positions within LOS. This case depicts the common case of vehicles moving on the same road along the same direction. In order to evaluate the

Table 1. Simulation Parametes.

Network Parameters	
Node Transmission Range	250m
Mac Layer	IEEE 802.11p Wave
PhyMode	Ofdm3mbs10MHz
Propagation Model	Winner B1 Model
Packet Size	256 Bytes
Packet Interval	0.01s
Flow duration	20 sec
Application	Udp UDP Server-Client

Scenario Settings	
Node Average Velocity	40 km/h
Node Max Velocity	65 km/h
Node Max Pause Time (traffic light)	5 sec
Node turn probability	0.5
RoadLength	150 m
RoadWidth	20 m

	Nodes	Hops	Grid (roads)	Area (m^2)
Scenario #1	50	2 - 4	3 x 3	500
Scenario #2	100	2 - 7	4 x 4	700
Scenario #3	150	3 - 10	5 x 5	800

routing performance in LOS scenarios, the sender and receiver nodes are either stable on the opposite edges of the same road or moving in the same road of the Manhattan grid area. The intermediate nodes are randomly placed and moving to random directions in the grid. This set of experiments triggers the mode1 of the proposed mechanism.

The second set of experiments evaluates the performance of the studied and proposed routing protocols in the case of NLOS between the sender and final receiver. In this set, during the whole transmission, the sender and receiver maintain positions that are in NLOS. This case depicts a challenging scenario as the sender and final receiver are located and moving on different roads for the whole packet transmission. In this set of simulations, the sender and receiver nodes are either stable in different roads or moving in different roads of the Manhattan grid area. The intermediate nodes are again randomly placed and moving to random directions in the grid. This set of experiments triggers the mode2 and mode1 (for less common cases where the previous hop is in LOS with the destination) of the proposed mechanism.

5 Results and Discussion

The first set of experiments has been conducted for the case where the sender and the receiver are in a line-of-sight (i.e. they are both in the same street in the Manhattan grid). This mostly presents the best case scenario for all algorithms and is used to set a base of what performance each algorithm can achieve without complicating the examined scenario.

Figure 8 shows the average (over the different simulation runs) packet delivery ratio achieved by each routing protocol, for the case there is line-of-sight between the sender and the receiver. In accordance with the results from [3], the worst performer or this case is AODV, for all the different Manhattan grid sizes. The delivery ratio of GPSR is better that the delivery ratio of the other existing routing protocols, and this is due to the knowledge of the positions of the neighboring nodes that the protocol takes advantage of to select as the next hop the node closer to destination. As the existence of the buildings should not play a major role in this case, GPSR makes good choices and maintain a high delivery ratio. However the proposed modification to the GPSR protocol boosts the delivery ratio quite higher than the unmodified GPSR and is the best performer in terms of the packet delivery ratio achieved.

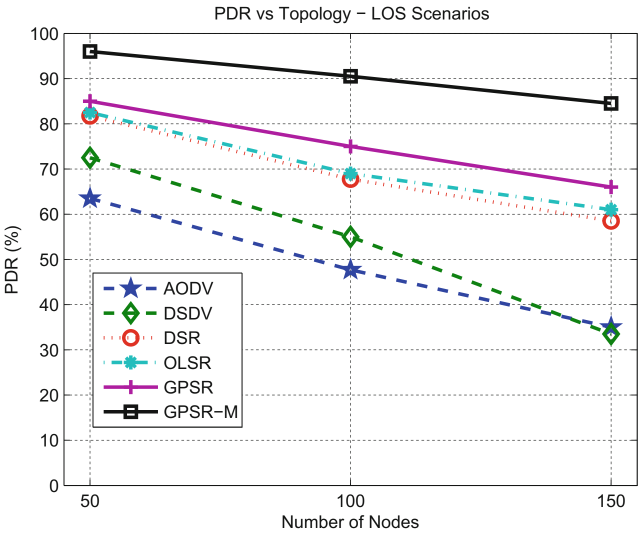


Fig. 8. Packet delivery ratio, for the case of line-of-sight between sender and receiver.

It should be noted that the delivery ratio drops as the size of the grid and the number of the nodes increase (maintaining almost the same node density). This is due to the fact that with larger grids more hops are required and the chances that there is a "gap" without intermediates, in the line-of-sight, becomes bigger and bigger and in that case the route has to make a "detour", which is no longer a simple case. The effect will be more evident with the end-to-end delay. However it is worth noting that the rate that the delivery ratio drops, as the grid increases in size, is less for the proposed modification to the GPSR protocol.

Figure 9 shows the average (over the different simulation runs) end-to-end delay achieved by each routing protocol, for the case there is line-of-sight between the sender and the receiver (please note that the ordering of the routing protocols and the grid sizes is different from the previous figure, so that larger bars do not obscure smaller ones). It should be noted that end-to-end delay increases rapidly with the size of the grid and the number of nodes (while node density remains almost the same). As already mentioned this is due to the "gaps", without nodes, that appear in the line-of-sight and require that another route is formed that detours the "gap". As already hinted this is not easily done in the urban setting, and for larger grid this case starts to look more like the case where there is no line-of-sight between the sender and the receiver.

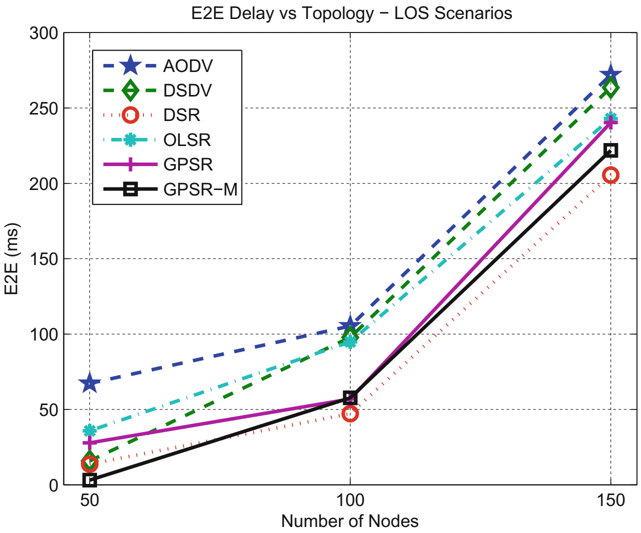


Fig. 9. End-to-end delay, for the case of line-of-sight between sender and receiver.

Having said that, for the small grid the best performer is the proposed modification to the GPSR protocol, and for the large grid the best performer is DSR. This can be explained by the fact that the GPSR-M protocol, maintains routes that deliver more packets even if for some of them the delay is large; i.e., there is a tradeoff between delivery ratio and delay. Still the proposed modification to the GPSR protocol manages to have better end-to-end delay than the rest of the routing protocols concerned.

Figure 10 shows the average (over the different simulation runs) power consumption for each routing protocol, for the case there is line-of-sight between the sender and the receiver (again, note the ordering of the routing protocols and the grid). The less power is consumed by the use of the DSR protocol. AODV, OLSR, GPSR and the proposed modification to the GPSR demonstrate a similar power usage. For the proposed modification to the GPSR protocol this means that the modifications can provide their benefits without increasing the power consumption.

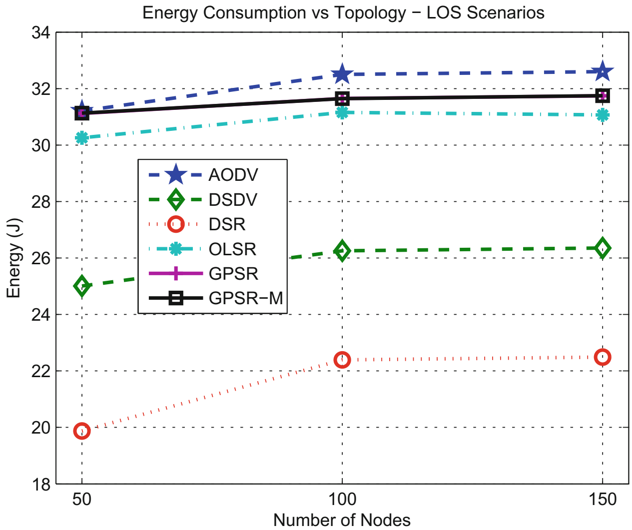


Fig. 10. Power consumption, for the case of line-of-sight between sender and receiver.

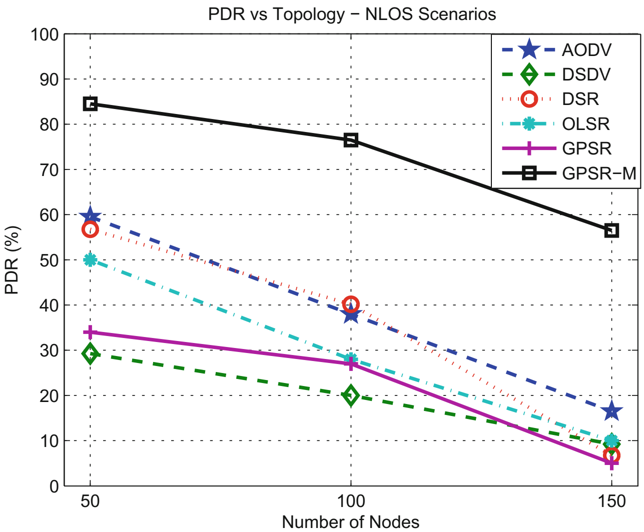


Fig. 11. Packet delivery ratio, for the case there is no line-of-sight between sender and receiver.

The second set of experiments where done for the generic (and more interesting) case where there is no line-of-sight between the sender and the receiver (i.e. they are in different streets in the Manhattan grid). This presents the most usual case for all algorithms.

Figure 11 shows the average (over the different simulation runs) packet delivery ratio achieved by each routing protocol, for the case there is no line-of-sight between the sender and the receiver. In this case the worst performer is DSDV, with second-worst the GPSR protocol. However the proposed modification to the GPSR protocol achieves more than double delivery ratio, and makes the GPSR-M the best performer with respect to the delivery ratio. This is explained by the fact that GPSR-M favors as intermediate nodes the vehicles that are (at the time of the transmission) in a crossroad and are more suited to route packets within the Manhattan grid. The original GPSR protocol greedily selects the node closer to the destination without taking into account if packets can be forwarded from there. As in the previous case the packet delivery ratio decreases for all routing protocols as the grid size increases. However, the improvement that GPSR-M achieves over the other protocols increases with the grid size (for the large grid is almost triple of the second best).

Figure 12 shows the average (over the different simulation runs) end-to-end delay achieved by each routing protocol, for the case there is no line-of-sight between the sender and the receiver. The end-to-end delay of GPSR-M is on the same level as the DSR and the AODV protocols, but the best performer is the OLSR protocol. Still GPSR-M greatly enhances the end-to-end delay of the GPSR protocol. As in the previous case the fact that GPSR-M has a much greater delivery ratio impacts the average end-to-end delay.

However, the overall performance of the proposed modification to the GPSR protocol is deemed higher than the performance of the remainder routing protocols, as the delivery ratio is more important that the end-to-end delay, and the resulting tradeoff is more than acceptable.

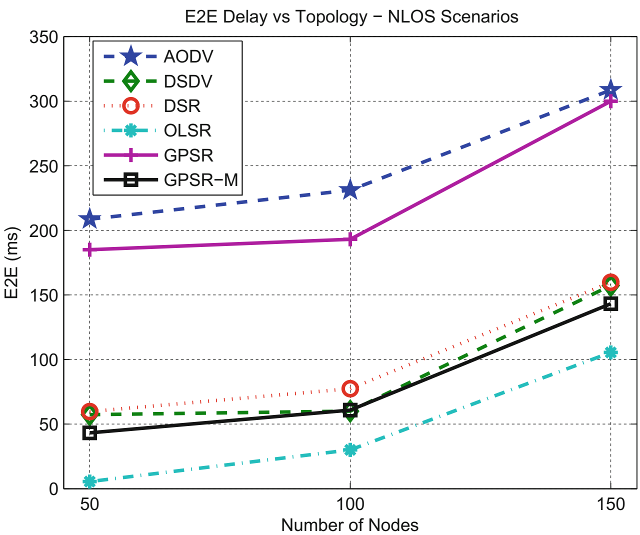


Fig. 12. End-to-end delay, for the case there is no line-of-sight between sender and receiver.

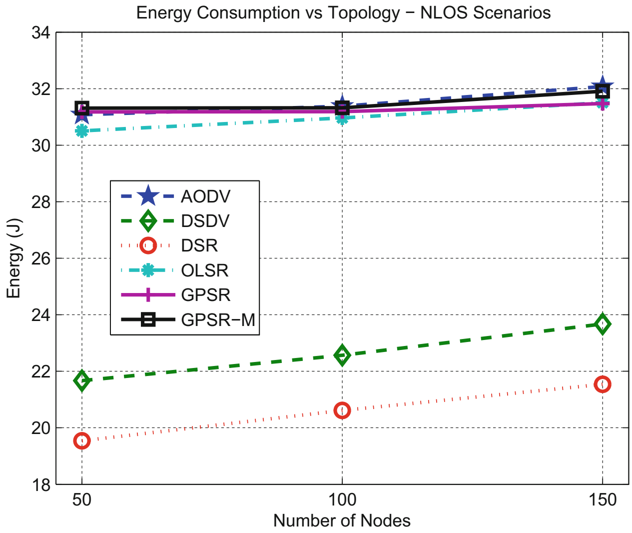


Fig. 13. Power consumption, for the case of no line-of-sight between sender and receiver.

Figure 13 shows the average (over the different simulation runs) power consumption of each routing protocol, for the case there is no line-of-sight between the sender and the receiver. Again, the less power is consumed by the use of the DSR protocol. AODV, OLSR, GPSR and the proposed modification to the GPSR demonstrate similar power usage. For the proposed modification to the GPSR protocol this means that the modifications can provide their benefits without increasing the power consumption.

The overall results demonstrate that the proposed mechanism greatly improves the GPSR performance for both LOS and NLOS scenarios and outperforms the other examined routing protocols. In all cases, the modified GPSR achieved higher packet delivery ratio and maintained quite satisfactory results even in very challenging scenarios of NLOS cases. Therefore, the proposed enhancement is a strong contender to be implemented together with GPSR.

6 Conclusions and Future Work

In this work we presented an experimental performance evaluation of routing mechanisms in MANETs, using simulation, for the case of VANETs within an urban environment (modeled by Manhattan grid). We also described and evaluated an enhancement of the GPRS protocol that takes into account the motion of the vehicles to estimate their position at future times, as well as the nature of the urban environment (i.e. the grid, in order to favor vehicles at crossroads as the intermediary nodes).

The simulation results have demonstrated that the performance of VANETs in an urban setting (with lots of buildings obstructing direct communications) is not satisfactory for a wide range of routing protocols. This is due to the reduced number of direct links that can be utilized in such a setting.

Still the proposed enhancement to the GPSR protocol manages to significantly increase the delivery ratio without increase power consumption; nevertheless, in some cases the higher delivery ratio is achieved at the expense of slightly increased end-to-end delay.

The main conclusion is that the characteristics of the urban setting can be exploited in order to come up with better routing strategies. However, the limitations imposed by the nature of the network topology are not clear, as it is not clear how far the performance increase can go.

Thus, our future work includes understanding better the problem, and proposing and evaluating new routing schemes that can perform much better in an urban setting.

In addition, we plan to incorporate sophisticated mobility prediction algorithms and mechanisms [4,20] in our work, and use these predictions to influence and improve the routing logic.

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References

1. Abbas, S.F., Chaudhry, S.R., Yasin, G.: VANET route selection in urban/rural areas using metric base traffic analysis. In: UBICOMM 2013, The Seventh International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies, pp. 85–91 (2013)
2. Aschenbruck, N., Ernst, R., Gerhards-Padilla, E., Schwamborn, M.: BonnMotion: a mobility scenario generation and analysis tool. In: Proceedings of the 3rd International ICST Conference on Simulation Tools and Techniques (ICST), p. 51, March 2010. http://dl.acm.org/citation.cfm?id=1808143.1808207
3. Bouras, C., Kapoulas, V., Tsanai, E.: A GPSR enhancement mechanism for routing in VANETs. In: Proceedings of the 13th International Conference on Wired & Wireless Internet Communications (WWIC 2015), Málaga, Spain, 25–27 May 2015
4. Gavalas, D., Konstantopoulos, C., Mamalis, B., Pantziou, G.: Mobility prediction in mobile ad-hoc networks. In: Pierre, S. (ed.) Next Generation Mobile Networks and Ubiquitous Computing, pp. 226–240. IGI Global, Hershey (2010)
5. He, G.: Destination-sequenced distance vector (DSDV) protocol. Helsinki University of Technology, Networking Laboratory (2002)
6. Jacquet, P., Mühlethaler, P., Clausen, T.H., Laouiti, A., Qayyum, A., Viennot, L.: Optimized link state routing protocol for ad hoc networks. In: IEEE International Multi Topic Conference. pp. 62–68 (2001)
7. Johnson, D.B., Maltz, D.A.: Dynamic source routing in ad hoc wireless networks. In: Imielinski, T., Korth, H.F. (eds.) Mobile Computing. The Kluwer International Series in Engineering and Computer Science, vol. 353, pp. 153–181. Springer, Heidelberg (1996). http://www.springerlink.com/index/10.1007/b102605

8. Kaisser, F., Johnen, C., Vèque, V.: Quantitative model for evaluate routing protocols in a vehicular ad hoc networks on highway. In: Vehicular Networking Conference (VNC 2010), pp. 330–337. IEEE (2010)
9. Kakarla, J., Sathya, S.S., Laxmi, B.G., Babu, B.R.: A survey on routing protocols and its issues in VANET. Int. J. Comput. Appl. **28**(4), 38–44 (2011). http://www.ijcaonline.org/volume28/number4/pxc3874663.pdf
10. Karp, B., Kung, H.T.: GPSR: greedy perimeter stateless routing for wireless networks. In: Proceedings of the 6th annual international conference on Mobile computing and networking, pp. 243–254. ACM (2000)
11. Katsaros, K., Dianati, M., Tafazolli, R., Kernchen, R.: CLWPR - a novel cross-layer optimized position based routing protocol for VANETs. In: IEEE Vehicular Networking Conference (VNC), pp. 139–146 (2011)
12. Kim, J.H., Lee, S.: Reliable routing protocol for vehicular ad hoc networks. AEU-Int. J. Electron. Commun. **65**(3), 268–271 (2011)
13. Kumar, R., Dave, M.: A comparative study of various routing protocols in VANET. arXiv preprint. arXiv:1108.2094 (2011)
14. Kyösti, P., Meinilä, J., Hentilä, L., Zhao, X., Jämsä, T., Schneider, C., Narandzić, M., Milojević, M., Hong, A., Ylitalo, J., Holappa, V.M., Alatossava, M., Bultitude, R., de Jong, Y., Rautiainen, T.: WINNER II Channel Models. Technical report, EC FP6 (2007). http://www.ist-winner.org/deliverables.html
15. Lee, K.C., Lee, U., Gerla, M.: Survey of routing protocols in vehicular ad hoc networks. In: Advances in vehicular ad-hoc networks: Developments and challenges, pp. 149–170 (2010)
16. Maan, F., Mazhar, N.: MANET routing protocols vs mobility models: a performance evaluation. In: 2011 Third International Conference on Ubiquitous and Future Networks (ICUFN), pp. 179–184 (2011)
17. Martinez, F.J., Toh, C.K., Cano, J.C., Calafate, C.T., Manzoni, P.: Realistic radio propagation models (RPMs) for VANET simulations. In: Wireless Communications and Networking Conference (WCNC 2009), pp. 1–6. IEEE (2009)
18. Nzouonta, J., Rajgure, N., Wang, G., Borcea, C.: VANET routing on city roads using real-time vehicular traffic information. IEEE Trans. Veh. Technol. **58**(7), 3609–3626 (2009)
19. Perkins, C., Belding-Royer, E., Das, S.: Ad hoc On-Demand Distance Vector (AODV) Routing (2003). http://www.ietf.org/rfc/rfc3561.txt
20. Su, W., Lee, S.J., Gerla, M.: Mobility prediction and routing in ad hoc wireless networks. Int. J. Netw. Manag. **11**(1), 3–30 (2001). http://dx.doi.org/10.1002/nem.386
21. Wan, S., Tang, J., Wolff, R.S.: Reliable routing for roadside to vehicle communications in rural areas. In: IEEE International Conference on Communications (ICC 2008), pp. 3017–3021. IEEE (2008)