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Junction-Based Geographic Routing Algorithm for Vehicular Ad hoc Networks

Sotirios Tsiachris · Georgios Koltsidas · Fotini-Niovi Pavlidou

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Abstract Vehicular Ad hoc Networks have attracted the interest of the scientific community, since many issues remain open, especially in the research area of routing techniques. In this work we propose a new position-based routing algorithm called Junction-Based Routing. The algorithm makes use of selective greedy forwarding up to the node that is located at a junction and is closer to the destination. If a local optimum is reached, a recovery strategy is applied, the key point of which is our proposed minimum angle method. We evaluate the performance of our routing protocol in real city topology. The simulated scenarios use obstacle modelling and several different Physical layer settings. Simulation results show that our proposal achieves superior performance compared to the well-known Greedy Perimeter Coordinator Routing algorithm.

Keywords Vehicular networks · Geographic routing · Position-based · Junction-based

1 Introduction

Vehicular Ad hoc Networks (VANETs) have attracted the interest of the scientific community, since they provide vehicles with the capabilities of the new generation wireless networks. VANETs are a special type of Mobile Ad hoc Networks (MANETs), but have several properties that distinguish them, the most important one being nodes' high mobility. This means that the probability of network partitions is higher and end-to-end connectivity is not guaranteed. However, although VANETs have dynamic topologies, these topologies are not completely random. The movement of nodes in a VANET is relatively predictable because it is restricted

S. Tsiachris · G. Koltsidas (✉) · F.-N. Pavlidou
Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki,
54124 Thessaloniki, Greece
e-mail: fractgkb@auth.gr

S. Tsiachris
e-mail: stsiachris@gmail.com

F.-N. Pavlidou
e-mail: niovi@auth.gr

to the roads on which the vehicles travel and this has both advantages and disadvantages. The predictability of the position of a vehicle allows an improvement in link selection, but the linear topology of VANETs reduces the possible path redundancy. The bandwidth is also exacerbated due to intersections, traffic jams and the presence of buildings, especially in an urban environment. Last but not least, VANETs have the potential to grow to a very large scale [1].

A key point of the success of such networks seems to be the appropriate routing algorithm. In [2] routing protocols are classified into five categories: ad hoc, cluster-based, broadcast, geocast and position-based. However, position-based or geographic routing tends to be the predominant one, since vehicles' movement is restricted along streets and, thus, information obtained from street maps, traffic models or more navigational systems on-board the vehicles can be useful. This fact is further documented by a number of studies that compare the performance of topology-based routing (such as AODV [3] and DSR [4]) against position-based routing strategies in urban as well as in highway traffic scenarios [5,6].

In this work we present a new geographic routing algorithm, whose main logic is to forward the data packets from junction to junction as far as possible, to quickly reach the destination node using the greedy forwarding, and switching to a recovery mode when a local optimum is reached. Therefore, our proposal was called Junction-Based Routing, or JBR for short. The key novelty of JBR is the minimum angle method for determining the appropriate next hop, while being at a recovery mode, which provides an accurate and safe solution, that is applicable in all cases, regardless of the relative position of source, destination and intermediate nodes.

The remainder of this paper is organized as follows. The next section overviews some routing protocols proposed so far, while in Sect. 3 we give a detailed description of JBR. In Sect. 4 we present the results of the protocol's evaluation compared to GPCR. Finally, Sect. 5 concludes the paper and proposes some future work.

2 Related Work

Even though VANETs represent a new technology, various geographic routing protocols have been proposed the last years. Initially, some classical geographic routing algorithms are presented, like GPSR [7] (Greedy Perimeter Stateless Routing) and GSR [8] (Geographic Source Routing) which are some early works and along with DGR [9] (Directional Greedy Routing), PGDR [9] (Predictive DGR) and GPCR [10] (Greedy Perimeter Coordinator Routing), they use greedy routing mechanisms. A-STAR [5] (Anchor-based Street and Traffic Aware Routing), MDDV [11] (Mobility-Centric Data Dissemination Algorithm for Vehicular Networks) and GyTAR [12] (Greedy Traffic Aware Routing protocol) exploit traffic information for better performance. Other protocols attempt to predict single-link or path connectivity, like Connectivity-Aware Routing (CAR) [13], IGRP [14] (Intersection-based Geographical Routing Protocol) and TOPOCBF [15] (Road Topology-Aware Contention-Based Forwarding, or predict vehicles' mobility, like VADD [16] (Vehicle-Assisted Data Delivery).

One early work on position-based protocols is GPSR [7] (Greedy Perimeter Stateless Routing). The protocol combines greedy routing with face routing, by using face routing to get out of the local minimum wherever greedy routing fails. It performs well in a free open space scenario with evenly distributed nodes. However, when applied to city scenarios for VANETs, GPSR faces critical performance degradation.

GSR [8] (Geographic Source Routing) is a position-based routing protocol with topological information. The algorithm makes use of a street map in order to acquire a global knowledge of the city topology and a Reactive Location Service (RLS) to get the destination position. Given this information, the algorithm first determines the junctions that have to be traversed by the packets and then applies greedy forwarding between them. Although GSR outperforms AODV and GPSR with respect to packet delivery ratio and average delay, it neglects the case that there are not enough nodes for forwarding packets when the traffic density is low.

In DGR [9] (Directional Greedy Routing), a position-based routing strategy, the nodes' moving directions are taken into account. Considering the fact that vehicles often have predictable mobility, PDGR [9] (Predictive Directional Greedy Routing) was also proposed to forward packets to the most suitable next hop based on both current and predictable future situations. Another greedy position-based routing is EBGR [17] (Edge Node Based Greedy Routing). In this algorithm packets are forwarded to nodes placed in the forwarding node's transmission range limit. The algorithm gives priority to nodes moving in the direction of the destination.

A well-known algorithm in the literature is GPCR [10] (Greedy Perimeter Coordinator Routing). It is a geographic routing algorithm that utilizes the fact that the nodes at a junction in the street follow a natural planar graph. Thus, a restricted greedy algorithm can be followed as long as the nodes are in a street, and junctions are the only places where actual routing decisions are taken. Therefore packets should always be forwarded to a node on a junction rather than being forwarded across the junction. Apart from the greedy routing strategy, when GPCR encounters a local optimum, it uses a repair strategy to get out of it. The repair strategy decides, on each junction, which street the packet should follow next using the right-hand rule. According to the right-hand rule the node in the junction chooses the street that is the next one counterclockwise from the street the packet has come from. After that, greedy routing is applied in between junctions in order to reach the next junction. The simulations show that GPCR has higher delivery rate than GPSR with higher average number of hops and slight increase in latency.

A-STAR [5] (Anchor-based Street and Traffic Aware Routing) is a routing algorithm that uses information on city bus routes to identify an anchor path with high connectivity for packet delivery. By using an anchor path, it guarantees to find an end-to-end connection even if traffic density is low. A-STAR also employs a route recovery strategy when the packets are routed to a local optimum by computing a new anchor path from the local maximum to which the packet is routed. The algorithm achieves obvious performance improvement compared with GSR and GPSR. However, the routing path may not be optimal because it is along the anchor path resulting in higher delay. Moreover, the concept of constant traffic information is only available in large cities.

Taking the traffic density into consideration, the authors in [11] proposed a position-based algorithm named MDDV (Mobility-Centric Data Dissemination Algorithm for Vehicular Networks). A forwarding trajectory is determined, which extends from source to destination (trajectory-based forwarding), along which a message will be moved geographically closer to the destination (geographical forwarding). The selection of the forwarding trajectory uses the geographical knowledge, whereas traffic density is assumed to be static. Messages are forwarded along the forwarding trajectory through intermediate nodes which store and forward messages opportunistically. However, the trajectory-based forwarding can lead to long delay if the traffic density varies by time.

GyTAR [12] (Greedy Traffic Aware Routing protocol) is an intersection-based geographical routing protocol capable of finding robust routes within city environments. GyTAR requires the existence of an accurate traffic information system in order to select appropriate paths. It takes into account the position of the junctions in order to decide the next hop for each packet. When a local optimum is encountered, the packet is carried by the vehicle until a junction is reached.

Another protocol is Connectivity-Aware Routing (CAR) [13], which attempts to combine characteristics from both geographic routing protocols, like GPSR [7], and ad hoc routing protocols, like AODV [3]. It consists of 4 main phases: path discovery, data forwarding, with the help of guards and error recovery. Although the simulation results show that its performance is very good, it is a relatively complex protocol, with many procedures, so that it adapts to the local conditions around each node and maintain paths towards the destination.

In [14] authors propose IGRP (Intersection-based Geographical Routing Protocol) where an effective selection of road intersections through which the packet must pass takes place. The selection of the road intersections is made in a way that maximizes the connectivity probability of the selected path while satisfying QoS constraints on the tolerable delay within the network, bandwidth usage, and error rate. Between any two intersections in the same path geographical forwarding is used so as to reduce paths sensitivity to individual node movements. Compared to GPSR, GPCR and OLSR [18], IGBR achieves significantly better performance. However simulations are performed in a custom discrete-event simulator in Matlab which introduces some difficulty on direct comparisons with other simulator results.

TOPOCBF [15] (Road Topology-Aware Contention-Based Forwarding) is a recently proposed routing protocol for VANETs which extends the CBF [19] algorithm. In this protocol routing path selection is based on a direct estimation of their multi-hop connectivity and not only on vehicular density obtained by real-time traffic information. Performance analysis takes place in a simulator called iTETRIS and TOPOCBF seems to achieve higher packet delivery ratio, and lower overhead compared to CBF and GEOUNICAST (basic iTETRIS protocol).

VADD [16] (Vehicle-Assisted Data Delivery) is a geographic routing protocol based on the idea of carry and forward by using predictable mobility specific to sparse networks. The next hop is chosen according to the highest pre-defined direction priority by selecting the closest one to the destination. VADD outperforms GPSR in terms of packet delivery ratio, average delay and overhead. Although this approach predicts the direction of vehicles' movement, it does not predict any future change in the topology.

GPCR algorithm has been used as an inspiration for our algorithm, since the idea of taking serious decisions at junctions is attractive and leads to better performance. In fact, junctions are the only places in a city road network that can communicate in 2 dimensions giving more alternative paths. However, GPCR comes with two major disadvantages.

In [10], the authors propose two methods to discover if a node is itself a coordinator or not. The first method requires each node to include its coordinates and the coordinates of its neighbors in the beacon messages sent regularly. However, this approach leads to beacon packets with increased length, and thus, it is considered inefficient. According to the second method, each node calculates a coefficient based on the positions of its neighbors. Although the latter technique neither needs any additional packets nor extends the length of the existing packets, in fact it is not so practical. This is because there are many cases where the calculation of the coefficient is either misleading (e.g. no nodes towards two opposite directions) or insufficient (e.g. when the junction has a form different from that of a cross).

Another issue related to the function of GPCR is the usage of the right-hand rule. According to that rule [20], the traversal of a phase in a planar graph is done as if we keep the right hand at the face. Based on this description and that of the GPCR, there are some cases where the right hand rule leads to routing loops (in the sense of road selection). For example, such a case takes place when the packet arrives at a local optimum from the south and the destination is on the east. Then, according to GPCR, the node at the local optimum will forward it towards the northern junction, where the decision is to use the southern route to forward the packet. This leads to a potential loop (in terms of nodes), since the same nodes may be used, or, seen from another point of view, to suboptimal routing.

Considering all the above described issues of GPCR, we developed a new algorithm, which we called Junction-Based Routing (JBR). The heart of our proposition is a new decision method adopted by the coordinators and regarding the streets and the nodes in particular that the data packets should be routed to.

3 Algorithm Description

3.1 Assumptions

Before describing the proposed algorithm, we need to provide some definitions and the assumptions our proposal is based on. We call *coordinator* every node located at a junction, and *simple node* every node placed in the middle of a road (i.e. between two junctions). We assume that every vehicle-node is equipped with a GPS device specifying its position. Generally speaking, GPS is currently a broadly available feature in automotive basic equipment. We also consider that every node is equipped with a digital map of the streets of the city where it moves. The combination of these two assumptions can offer information regarding whether one node is in a junction (and thus is a coordinator) or is placed in the middle of a road (and thus is a simple node). As a result, there is no need for extra beacon messages, like in GPCR, in order to indicate that a node acts as a coordinator. This is a great improvement over GPCR, which causes increased overhead and performance degradation.

Every node periodically broadcasts hello messages, which contain information about the node's coordinates. These messages have also a field called $iscoord\_$, where each node announces if it is a coordinator or not. Once a hello message is received, the receiving node stores the ID (or IP address), the co-ordinates and the $iscoord\_$ variable of the node that sent the message, as well as the timestamp at which the hello message was received. If a new hello message from the same node is received shortly, the receiving node simply updates its information in the list. But if a hello message from a node is not received within a certain period of time, then the registration of the particular node is deleted from the neighbors' list.

What is more, every node that wants to send a message to a destination, must know constantly the geographic position of the latter. For this purpose, we assume that each destination node floods periodic messages, called queries, which include its coordinates, so that the data source is aware of its position. One could optimize that procedure to overcome the flooding issue; however, the optimization of this procedure is out of the scope of this work.

3.2 Selective Greedy Forwarding

The basic idea of the common greedy forwarding techniques is to send the message to the neighbor that is located as far as possible from the forwarding node. Generally, the packet is forwarded to the node that is closer to the borders of the range area and is also closer to the destination.

In the JBR algorithm, selective greedy forwarding is used if no local optimums are encountered. In this technique the coordinators play the major role. At first, the algorithm checks whether the destination node is in range and if this is true, the packet is directly forwarded to it. If the destination is not inside the range, we follow the method described below.

3.2.1 Selective Greedy Forwarding from a Simple Node

If a simple node wants to forward a packet, it searches its list of neighbor for nodes that are closer to the destination than itself. Then the process divides them in available coordinators and simple nodes. If there are any available coordinators, they are checked in priority and the closest one to the destination is chosen as next hop. Random selection in that case could result in performance degradation as we will explain later. If there are no available coordinators then a simple node that is closer to the destination is chosen as next hop.

3.2.2 Selective Greedy Forwarding from a Coordinator

When a packet arrives at a coordinator in a junction, the latter has to decide which street to forward it onto. Initially, the neighbor list is checked and the neighbors that are closer to the destination than the current coordinator are selected. Then the selected neighbors are divided into coordinators and simple nodes. The only difference now is that we only keep coordinators placed at a different junction than the current one. First, the process checks the qualified coordinators, and the one closer to the destination is chosen. If there are no qualified coordinators, the algorithm checks the available simple nodes and chooses the one closer to the destination as the next hop.

Let us note that in GPCR, packets should stop at every junction, although coordinators in junctions closer to the destination may be in range. The main advantage of the way the coordinators are selected in JBR is that, in case there are two or more junctions in range, the packet is forwarded directly to the coordinator placed at the junction that is closer to the destination. This can be shown in Fig. 1: using GPCR, the packet from coordinator C3 would be forwarded to coordinators at every junction in range, i.e. C5 and C6, resulting in higher average delay. With JBR the packet is forwarded directly to coordinator C6 which is closer to the destination.

3.3 Recovery Strategy

Even with selective greedy forwarding, reaching a local optimum is something common in a city environment. In this case a recovery strategy should be used, so that the messages are routed around the obstacle and reach their destination. In JBR's recovery strategy, coordinators also play the main role.

There are two cases, depending on whether the forwarding node is a coordinator or a simple node. Every case is divided into two sub-cases; the node is the message source or a forwarding node. This separation is important, because if a node simply forwards a message, it needs the position of the last hop. On the other hand if a node is a message source, this information is meaningless since there is no last hop. Like in selective greedy forwarding, we first check if the destination is in range and if this is true, the packet is forwarded directly to it and no additional action should be taken.

3.3.1 Recovery Strategy from a Simple Node

Selective greedy forwarding from a simple node that is also a message source If a simple node—which is also a message source—reaches a local optimum, the neighbor list is considered and the neighbors are divided into coordinators and simple nodes. Then, from the

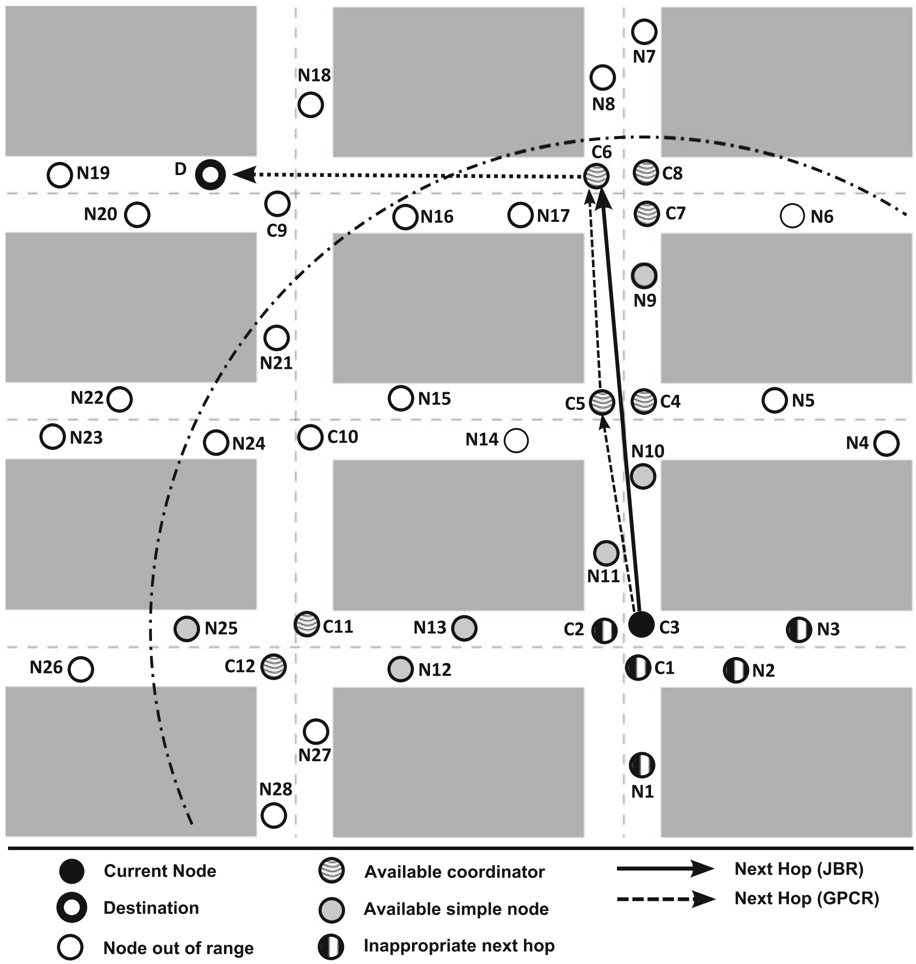

Fig. 1 Greedy forwarding from a coordinator

available coordinators the one closer to the destination is selected. If there are no coordinators available, the current node forwards the packet to the simple node that is closer to the boundary of the range limit.

Selective greedy forwarding from a simple node that just forwards a message In this case, the node searches into the neighbor list for nodes that are not placed behind it. In fact, it searches for nodes that are not placed in the direction from which the packet arrived. We consider that an arbitrary node is not behind the current node if

$$(nldis > cldis) \quad AND \quad (nldis > mndis), \tag{1}$$

where $cldis$ is the distance between the previous and current node, $nldis$ is the distance between the previous node and the node under consideration (potential forwarding node), and $mndis$ is the distance between the current node and the node under consideration.

Once this initial distinction is made, then the selected nodes are divided as usual into coordinators and simple nodes. The available coordinators are checked in priority and the one closer to the destination is selected as next hop. If there are no qualified coordinators, the available simple nodes are checked and the one further away from the local source is selected as next hop. The purpose of the above procedure is to get over the local optimum and find a coordinator as soon as possible.

3.3.2 Recovery Strategy from a Coordinator

Coordinators are the nodes that play the major role in recovery from a local optimum. In this section we actually address the second problem of GPCR having to do with the right hand rule. We overcome this problem by introducing the minimum angle method as part of our recovery strategy, which is described below.

Selective greedy forwarding from a coordinator that is also a message source In the case that a coordinator, being also a message source, is placed at a local optimum, it divides its neighbors into simple nodes and coordinators that do not belong to the same junction. The available coordinators are checked in priority and the one closer to the destination is selected as next hop. If no coordinators are available, the packet is forwarded to the furthest simple node from the forwarding node.

Selective greedy forwarding from a coordinator that just forwards a message A coordinator that is just a forwarding node has the most crucial and also the most complex decision to make. Initially the node checks whether or not the coordinator is on the same road with the destination.

If they are not on the same road, the coordinator first isolates the available neighbors that are not behind it. Then it divides the qualified neighbors into coordinators that do not belong to the same junction and simple nodes. The qualified coordinators are checked in priority and the one closer to the destination is selected. If no appropriate coordinators are found, like in the network of Fig. 2, then the process checks the qualified simple nodes and selects one using the minimum angle method, which is analyzed below.

We consider that the trigonometric circle agrees with the four signs of the horizon (North-y, South-Oy, West-x, East-Ox), so that all calculations have the same reference point which is independent from the geographic position and the movement direction of the vehicles. Initially, as we can see in Fig. 2, we calculate $sdangle$, i.e. the angle between the node that was first put into recovery strategy and the destination (in direction from the first to the second). The coordinator isolates the simple nodes that are not behind it. The next step, also shown in Fig. 2, is to calculate the angle of every simple node selected in the previous step. This is done in the trigonometric circle. The origin is placed on the node that was first put in recovery mode (S, in our example). This angle is called $snangle$. The last step is the calculation of the absolute difference of the $sdangle$ and $snangle$, which we call $minangle$.

$$minangle = |sdangle - snangle| \tag{2}$$

Finally, as next hop is selected the simple node with the smaller $minangle$. In our example of Fig. 2, it is obvious that the $minangle$ of node N5 is the smallest one compared to all the other available nodes and, thus, N5 is chosen from C2 as the next hop. In this way, among all

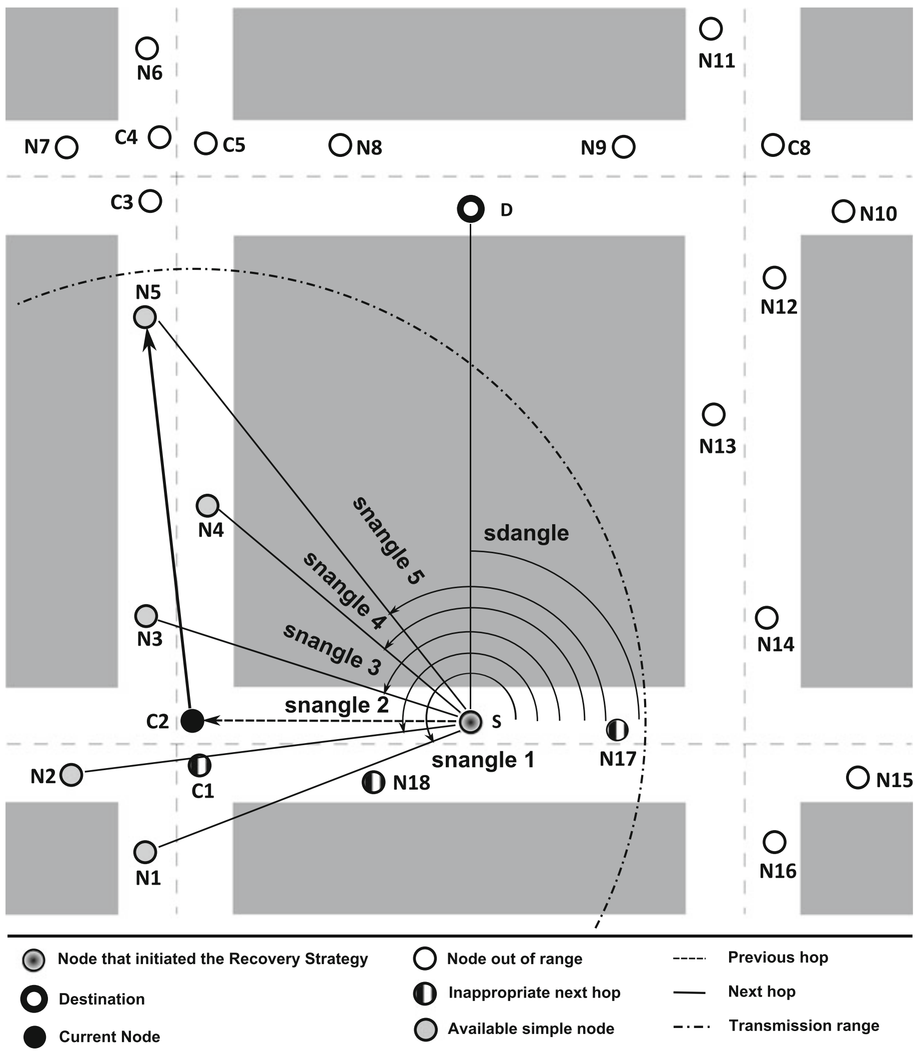

Fig. 2 Recovery mode from a coordinator

the available neighbors, the one that is further from the local optimum and closer to another coordinator is selected.

If the forwarding coordinator and the destination are on the same road, the former initially isolates the neighbors that are not behind it. Then, from the selected nodes, only those that are closer to the destination than the coordinator itself are selected. In fact, only the nodes that are placed along the part of the road that connects the coordinator and the destination remain. A third distinction follows, where the previously selected nodes are divided into coordinators belonging to different junctions and simple nodes. If there are any available coordinators, the one closer to the destination is selected as next hop. If there are not any, the packet is forwarded to the simple node that is closer to the destination.

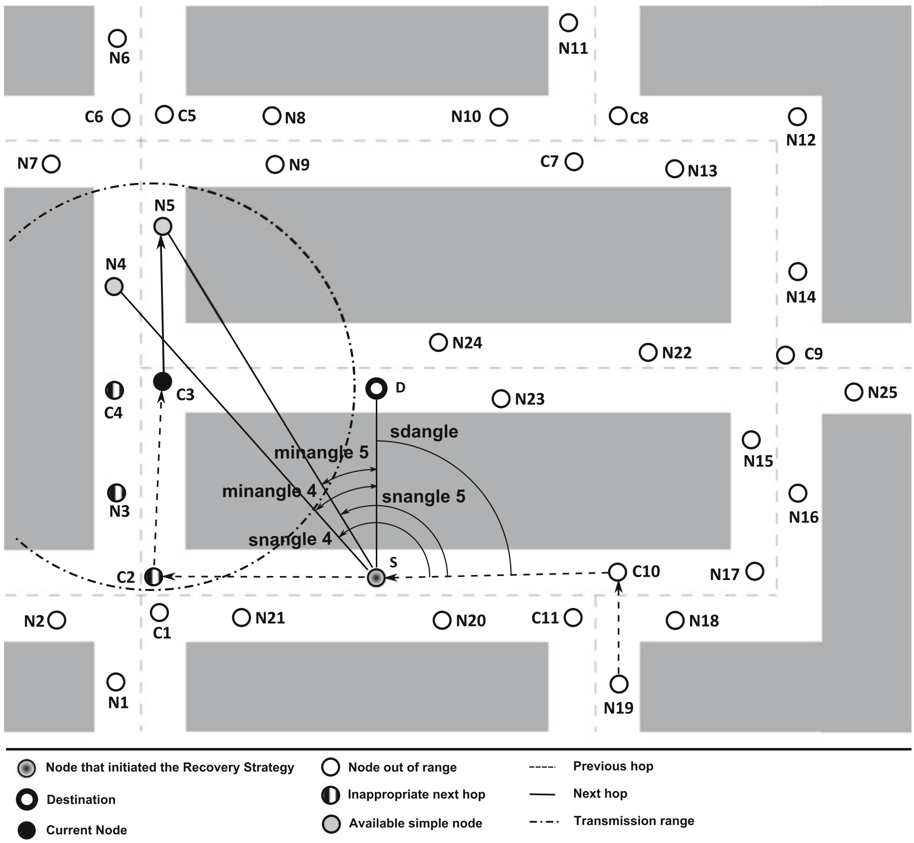

Fig. 3 Recovery strategy from a coordinator which is on the same road with the destination and there are neither available coordinators in different junctions nor simple nodes along the road towards the destination

However, there is a possibility that there are not any qualified coordinators or qualified simple nodes available, as shown in Fig. 3. This means that there are no nodes between the current coordinator and the destination. In this case, all the distinctions that were made above are cancelled and the minimum angle method is applied.

3.4 Overall Function of the JBR Algorithm

The proposed JBR algorithm combines selective greedy forwarding and a recovery strategy according to the following: the message source uses selective greedy forwarding and forwards the packet to the neighbor that is selected as next hop. The process continues in every forwarding node, until the packet reaches its destination. If the packet reaches a local optimum, the selective greedy forwarding technique does not find any neighbor as possible next hop and the recovery strategy is initiated. The recovery strategy is sustained until the packet is forwarded to a node that is closer to the destination than the node that first switched to recovery node. Then, the algorithm switches to selective greedy forwarding mode and the packet is forwarded towards the destination. In the rare occasion that there are not any

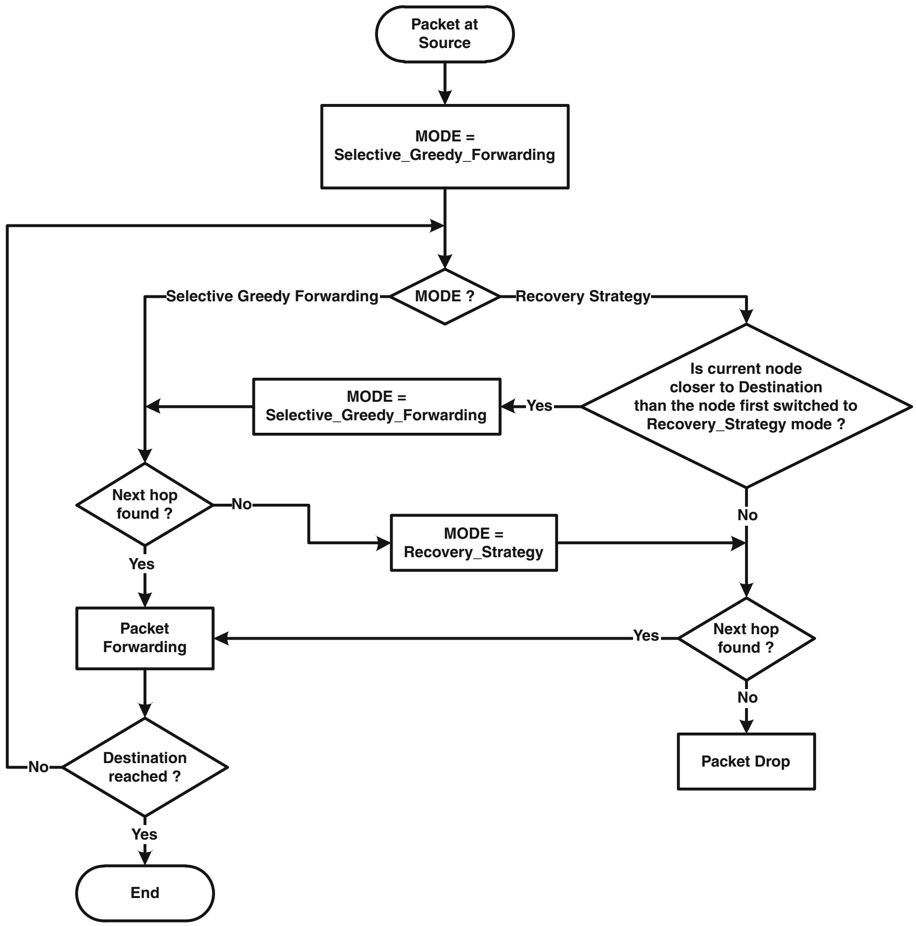

Fig. 4 Flowchart of the packet forwarding procedure

qualified neighbors to be selected as next hop, the packet is dropped. Figure 4 depicts a flowchart of the proposed algorithm's forwarding procedure.

4 Performance Evaluation

We evaluated the performance of JBR using the NS-2 [21] (version ns-2.34) and compared it to a modified version of GPCR. In this version of GPCR the identification of coordinators is assumed to follow the same technique as in JBR (use city maps and GPS device), so that the comparison is independent of the coordinator identification methodology. What is more, coordinators are randomly selected when a coordinator is about to forward a message. Finally, we used in GPCR also the minimum angle method, whether it is in the same road with the destination or not, because otherwise GPCR would lead to routing loops and the comparison with JBR would be unfair. We avoided comparing our protocol to other MANET routing protocols, since they are inappropriate for VANET environments.

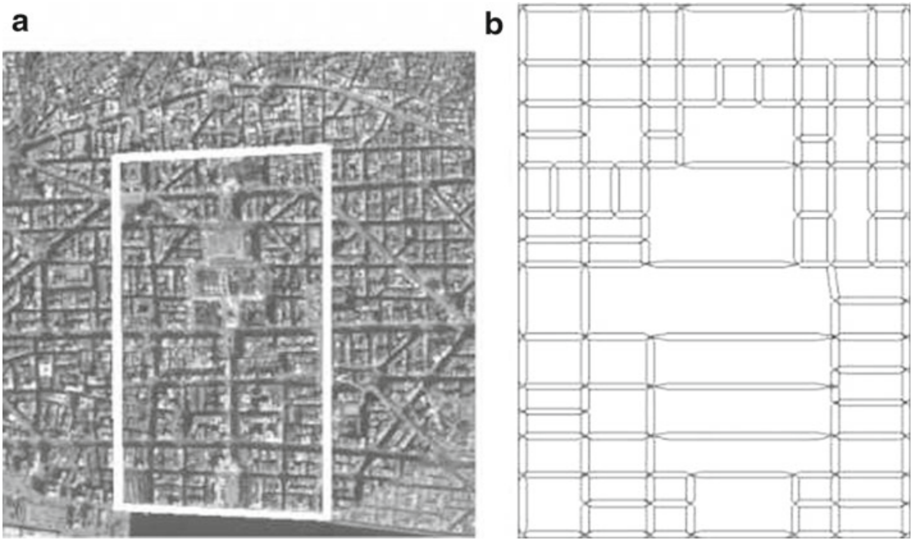

Fig. 5 Modelled area of Thessaloniki (Greece). The geographic coordinates of the selected area's centre is (40°38′9.08″ N, 22°56′39.24″ E)

For the generation of node movement we used the VanetMobiSim [22] vehicle traffic simulator, which is a VANET mobility extension to the CanuMobiSim [23] framework. For our simulations, an 1,150 m × 700 m area of the center of the city of Thessaloniki (Greece) was selected and modelled in VanetMobiSim. Figure 5a depicts the part of the city that was modelled and Fig. 5b its model in VanetMobiSim. The scenario consists of 300 vehicles moving according to the Intelligent Driver Model with Lane Changing (IDM-LC). In this model each vehicle's speed is based on movements of neighboring vehicles (e.g. if a car in front brakes, the succeeding vehicles also slow down). What is more, vehicles slow down and stop at intersections, act according to traffic lights if present and are able to change lane and perform overtakings in presence of multilane roads. We considered an average vehicle length of 5m and inter-vehicle distance of 2 m. We also set the minimum and maximum speed at 3 m/s (10.8 km/h) and 13.9 m/s (50 km/h). Initially vehicles start from different junctions and move towards the junctions of the outer part of the modelled area. When reaching a junction-destination, a vehicle moves to other outer junctions with different probabilities.

We modelled the blocking of signal transmissions by obstacles such as buildings around the city, by using a modified version of the Obstacle Mobility Model [24] for ns-2.34. Spaces between streets are assumed to be taken up by buildings and therefore radio waves cannot propagate through them. Thus, two nodes can communicate directly with each other when they are in their respective transmission ranges and also obey the "line of sight" criterion. Although the performance of unicast routing protocols can be reduced due to radio signal variability, as shown in [15], however, such a variability has not been modelled in our simulations, where the communication radius is considered the cumulative result of all parameters that affect radio signal propagation, and we assumed, as in the majority of other works, that this radius remains constant.

Among all vehicles, 20 of them were randomly chosen to send CBR data packets to other moving vehicles. Each CBR flow uses 512-byte UDP packets and sends at 4 packets per second rate. Each simulation lasts 1,000 s. The hello period is set to 0.25 s and if two successive

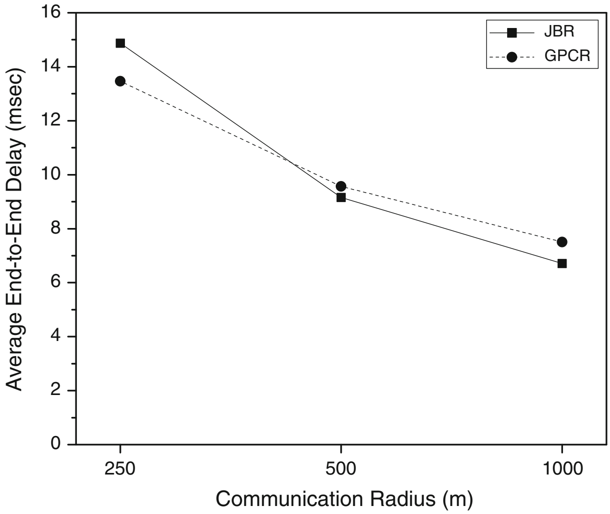

Fig. 6 Average end-to-end delay over the communication radius

hello messages are not received, the registration of the particular node is deleted from the neighbor list. The destinations send query messages every 2 s, the Two Ray Ground [25] is used as propagation model and we consider that the vehicles are equipped with isotropic antennas. In our effort to evaluate the performance of JBR and GPCR, we carried out a simulation set in which we compared the performance of the two protocols for 3 different values of the communication radius: 250, 500 and 1,000 m. We used IEEE 802.11p MAC protocol, as it is the most common choice for VANETs, at 5.9 GHz frequency and data rate equal to 6 Mbps. Table 1 summarizes the simulation settings.

In order to eliminate statistical errors, the results of five independent simulation runs were averaged out for each scenario examined. In each simulation run, different sending-receiving pairs were used. The key metrics of interest are (1) *Average end-to-end delay*: the average time it takes for a packet to traverse the network from source to destination; (2) *Packet delay distribution*: percentage of total delivered packets that were received within different end-to-end delay range groups; (3) *Packet delivery ratio (PDR)*: the ratio of the packets that successfully reached destination to the ones originally sent out; and (4) *Average Number of Hops* for the delivered packets.

The first metric we examined is average end-to-end delay and the results are shown in Fig. 6. From that figure it is easy to conclude that for high ranges, JBR achieves lower delay than GPCR. Using JBR the maximum observed value is approximately 14.9 ms (when communication radius is 250 m), while the lowest one is 6.7 ms and it corresponds to 1,000 m communication radius. For this last case, JBR achieves approximately 10 % lower delay than GPCR. The reason for the lower delay of JBR is that it resolves better the next hop on a path, enabling packets to reach destination faster. This is better observed in the case of the larger communication radius, where the potential next hop neighbours are increased in number and selection becomes more difficult. The reason why JBR presents higher delay for 250 m radius is related to the higher number of delivered packets and the higher average hops in this case, as it will be shown later.

In Fig. 7 we present the delay distribution in 11 time range groups: 0–10 ms, 10–20 ms, 20–30 ms, 30–40 ms, 40–50 ms, 50–60 ms, 60–70 ms, 70–80 ms, 80–90 ms, 90–100 ms

Table 1 Simulation parameters

Parameter	Value
Simulation area	1, 150 m × 700 m
Number of vehicles	300
Vehicle speed	3–13.9 m/s (10.8–50 km/h)
Packet senders	20
Communication type	CBR
Packet type	UDP
Packet size	512 bytes
CBR rate	4 packets/s
IFQ	50 packets
Simulation time	1,000 s
Hello period	0.25 s
Hello timeout	0.7 s
Query period	2 s
Propagation model	Two ray ground
Antenna gains (GT, GR)	0 dBi
MAC protocol	IEEE 802.11p
MAC data rate	6 Mbps
Frequency	5.9 GHz
Transmission range	250, 500, 1,000 m

and values >100 ms. For each range group we obtained the percentage (%) of the delivered packets within the specific delay range, with respect to the total delivered packets. In general, there is no great difference between the two protocols, regardless of the communication radius. In all occasions we can see that almost 90 % of the total delivered packets are received to the destination in <30ms. In addition, when we use a transmission range of 500–1,000 m, the percentage of packets that are received in this time interval is 98 and 99 % respectively. In general for a radius of 1,000 m, the curve for JBR is a bit sharper, with almost 84 % of the packets are delivered in <10 ms. Hence, any highly restrictive QoS delay criterion could be satisfied, provided that the traffic load and network area are taken into consideration.

The packet delivery ratio (PDR) results are presented in Fig. 8. The PDR of JBR is above 70 % and especially for the two higher radius values, it is almost 87 and 89 % respectively. On the other hand, in GPCR packet delivery ratio is much lower and ranges from 54 to 70 %, nevertheless its tendency is similar to that of JBR, i.e. it increases as radius increases.

As we mentioned earlier, when the communication radius is 1,000 m, the highest packet delivery ratio values are observed. This is explained by the fact that the wider the transmission range is, the less hops are needed for a packet to be delivered to its destination, and less packets are lost. What is more, the larger the transmission range is, the higher the probability of finding a next hop towards the optimum direction. Similarly, end-to-end delay seems to be the lowest for a radius of 1,000 m, which is reasonable due to the fewer hops that are needed for the packets to be delivered.

Finally, the average hops needed for packets to reach their destinations are shown in Fig. 9. As expected, the number of hops decreases when the communication radius increases. The value of 500 m for the radius seems to be a critical point, since the number of hops falls rapidly in this case, with respect to the previous one. When changing from 500 to 1,000 m,

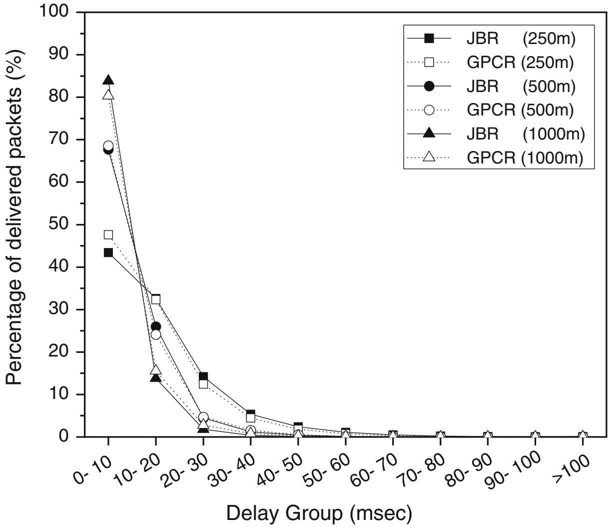

Fig. 7 Packet delay distribution, as a percentage of the total delivered packets

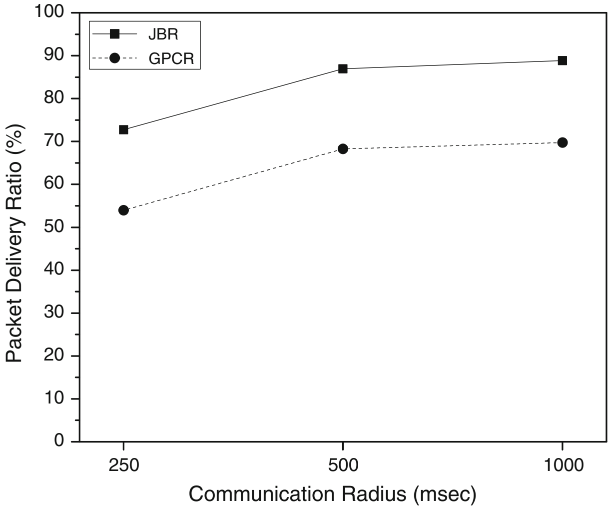

Fig. 8 Packet delivery ratio over the communication radius

the decrease is lower, however it is significant as well. For the highest range, JBR achieves relatively smaller values for the number of hops, while the opposite is true for the lowest transmission range. The latter is also related to the higher PDR achieved by JBR, since packets further away are usually more difficult to reach. In this way, the higher delay values for the 250 m range case are explained: more packets are delivered using a bit longer paths, achieving to reach destinations that are in average further than in the case of GPCR, which shows that JBR responds to topology changes in a way that it finds more correct routes towards the destinations and manages to deliver more packets to them.

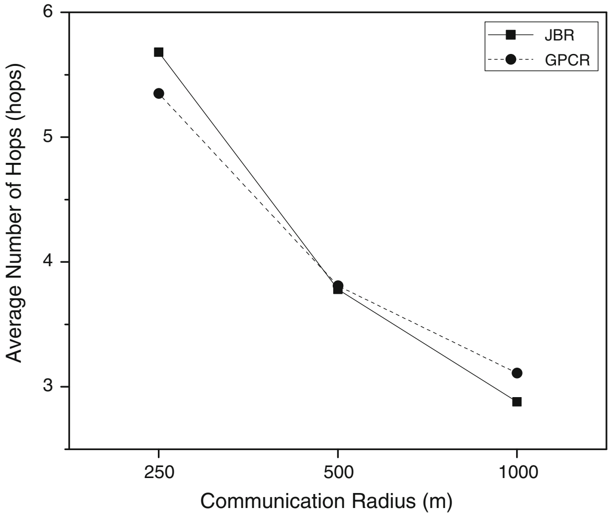

Fig. 9 Average number of hops over the communication radius

We also run a second simulation series in which we measured the performance of the two algorithms for 6 different maximum speeds of the moving vehicles: 0 km/h (static nodes), 20, 35, 50, 75 and 90 km/h. In this set of simulations, a communication radius of 500 m was used. The results revealed that the average end-to-end delay and PDR remain relatively constant for both protocols despite the maximum speed's increase. One should expect to see a much worse performance at very high speeds, but this did not occur. This happens because nodes' average speeds differ a lot from the nominal maximum ones, due to stops at junctions and traffic lights. These two phenomena are the cause of an average vehicle speed much lower than the nominal maximum value, and this average speed does not differ a lot from case to case. Hence, the results are similar with each other (which is the reason we decided not to provide any graph for them). Actually the maximum speed can only be achieved at high ways and long roads without intersections. In any other case, it is the average node speed that is of importance.

5 Conclusions and Future Work

In this paper, we proposed a position-based routing algorithm for VANETs called Junction-Based Routing (JBR). The main idea is the exploitation of the nodes placed at junctions. The algorithm uses a selective greedy forwarding in collaboration with a recovery strategy. We also introduced the novel minimum angle method, which is part of the recovery strategy. Our proposal presents interesting results concerning end-to-end delay, delay distribution and packet delivery ratio, outperforming the GPCR routing algorithm in most cases. Finally, we noticed that both JBR's and GPCR's metrics are only slightly affected by changes of the maximum vehicle speed in urban environments; what really matters is the average speed. We also concluded that better performance is achieved with higher transmission ranges. In future we intend to examine the performance of our algorithm in scenarios with larger areas, that allow vehicles to have an increased average speed and more random street topologies.

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Author Biographies

Sotirios Tsiachris received his Diploma from the Department Electrical and Computer Engineering of Aristotle University of Thessaloniki, Greece in 2010. His research interests fall into the area of routing algorithms design for vehicular ad hoc networks.

Georgios Koltsidas received his Diploma and PhD degree from the Department Electrical and Computer Engineering of Aristotle University of Thessaloniki, Greece in 2003 and 2009 respectively. His major research interests include efficient routing protocol design for mobile ad hoc and sensor networks and adaptive resource management techniques for wireless networks. He has also been involved in many national and European research projects.

Fotini-Niovi Pavlidou received the Diploma degree in Mechanical/Electrical Engineering and the PhD degree from the Aristotle University of Thessaloniki (AUTh), Greece, in 1979 and 1988 respectively. She is now a Full professor at the department of Electrical and Computer Engineering in AUTh where she is engaged in research, lectures, laboratory courses and supervision of Doctorate dissertations in Mobile Communications, Telecommunications Networks and Satellite Communications. Her research interests include traffic analysis and design (MAC protocols and routing techniques) of wireless (terrestrial, satellite, ad hoc, sensor) networks, performance evaluation and QoS studies of mobile satellite communications and multimedia applications over the Internet. She is the author of more than 150 papers in international journals and conferences. She is a permanent reviewer in many IEEE/IEE and other international journals, has been involved in various editorial activities, she is a reviewer for book publishers, reviewer for research projects for various funding organizations. She is permanently included in the Technical Program Committee of many IEEE conferences and has been the organizer and Technical Program Chair of a number of conferences. Prof. Pavlidou is involved in many European and National Projects. Prof. Pavlidou has held several academic and consolatory positions. She is a member of the Board of Directors in the Research Academic Computer Technology Institute, Patras Greece. She has been the Delegate of Greece in the European COST Program on Telecommunications (1998–2004) and served as Chairperson for the COST262 Action “Spread Spectrum systems and techniques for wired and wireless Systems”. She currently serves as an Expert for Greece in the FP7 Cooperation Program in the ICT theme (2007-), and as a representative of GSRT in the Public Authorities Board (PAB) of the ARTEMIS Joint Undertaking (2008-). She is a Senior Member of IEEE (Communications and Vehicular Technology Society).