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Applicability of position-based routing for VANET in highways and urban environment

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ABSTRACT

In the last years many routing protocols proposals have been made considering the particular VANET characteristics. From the many proposals that came up, the protocols based on the vehicles positions were found to be the most adequate to VANETs due to their resilience to handling the nodes position variation. In this study we will survey the existing position-based routing protocols. Unlike other studies we will emphasise on their applicability to different environments. We start by characterising the vehicular network environment, namely the urban and the highway environments. Afterwards, topology-based protocols are compared to position-based protocols and to the latter are identified the different used strategies and their performances are qualitatively evaluated relatively to different metrics. The different position-based routing proposals are described including a pseudo-code specification, and a comparison is made based on different perspectives. To conclude, the main constrains to urban and highway environments are characterised and the adaptability of each protocol to each of the environments is evaluated.

1. Introduction

Recent advances in wireless technologies and embedded systems extended the use of communications to new domains. Taking advantages of such technological advances, vehicle and equipment manufacturers have recognised the opportunity of enhancing the surface transportation by using the communication capabilities of the Vehicular Ad-hoc Networks (VANET) to offer an Intelligent Transportation System (ITS) to the drivers. The major goal of this system is to improve the drivers safety by informing them about dangers and situations that they cannot see. It will also be used to support other services such as broadcast of weather or traffic conditions or infotainment to make a trip more pleasant to the passengers (Research and Innovative Technology Administration (RITA), 2009; ETSI, 2009). In Toor et al. (2008) the most relevant applications have been surveyed and the major technical challenges identified showing that major modifications are needed in all the layers of the Open Systems Interconnection (OSI) reference model. To support such variety of services, ITS will provide communication amongst vehicles, between vehicles and the roadway infrastructure and from latter to vehicles and wireless devices that are carried by drivers, pedestrians and cyclists.

Due to the well-defined mobility pattern of the nodes and characteristics of the surrounding environment, most of the solutions that have been proposed for Mobile Ad-hoc Networks (MANET) are not suitable for VANET (Füßler et al., 2003; Selvaretnam and Wong, 2004). In Hartenstein and Laberteaux (2008) it is shown that the different type of applications, the resources and the environment make VANET a unique area of wireless communication.

Thus, a significant effort is being put to design solutions for this new type of environment by the industry, standardisation bodies and the research community, as surveyed in Papadimitratos and La Fortelle (2009). Since 2000, a significant number of research projects developed by car manufacturers in consortium with other entities have been funded either by national agencies or international entities. These projects aim at promoting energy efficiency and road safety. The first ones were focused on the design of autonomous systems aimed to improve the transport infrastructure or the vehicles themselves. A few examples can be represented by the Network on Wheels (NoW) (Festag et al., 2008), Fleetnet (Hartenstein et al., 2001) and CarTALK 2000 (Reichardt et al., 2002). More recently, projects were focused in cooperative systems based on vehicle-to-vehicle and vehicle-to-infrastructure communications, rather than in autonomous systems (Toulminet et al., 2008): CVIS (Cooperative Vehicle-Infrastructure Systems) aimed to define a unified architecture and a wide range of cooperative

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services and applications; SAFESPOT aimed to create dynamic cooperative networks that increased road safety through the drivers' perception of the neighbourhood; and COOPERS (Co-operative Systems for Intelligent Road Safety) aimed to enhance the road safety through the development of cooperative traffic management applications. eCoMove is an ongoing project that aims to use vehicle cooperation for a more eco-friendly driving. Also, important automobile manufacturers have joined their efforts and created a non-profit organisation, the Car2Car Communication Consortium (C2CCC), which aims at increasing road safety and traffic efficiency through the use of VANET communications.

A major result of these efforts, promoted by the COMeSafety initiative, is the coordination and consolidation of the scientific results that lead to the definition of a common reference architecture with a direct commitment of standardisation bodies, such as European Telecommunications Standards Institute (ETSI) TC ITS and the International Organization for Standards (ISO) TC204 WG16 (ITS Communications). This architecture, the Communication Access for Land Mobile (CALM), described in Initiative (2006) and briefly surveyed by Kosch et al. (2009) was been adopted in Europe since then. CALM defines a set of wireless communication protocols and air interfaces for a variety of communication scenarios of ITS, decoupling applications from the communication infrastructure.

Another important contribution was made by the Institute of Electrical and Electronics Engineers (IEEE) with the standardisation of the Wireless Access in Vehicular Environments (WAVE), a complete protocol stack and architecture specifically designed for VANET, which is described in the set of standards IEEE 1609 (IEEE trial-use standard for wireless access in vehicular environments (wave) – resource manager, 2006a; IEEE trial-use standard for wireless access in vehicular environments – security services for applications and management messages, 2006b; IEEE trial-use standard for wireless access in vehicular environments (wave) – networking services, 2007; IEEE trial-use standard for wireless access in vehicular environments (wave) – multi-channel operation, 2006c). In the context of this standardisation work a new IEEE standard was defined for PHY and MAC layers, 802.11p (Jiang et al., 2008). In spite of the advantages of using 802.11p, several studies suggested that it has several performance problems (Bilstrup et al., ; Eichler, 2007). When using the different access classes provided by 802.11p messages can be prioritized. However, the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) does not guarantee channel access before a fixed deadline and so one can not ensure time critical message dissemination. Therefore, unacceptable channel access delay can be experienced, specially in dense regions or heavy traffic conditions.

For more than one decade research community is been also actively contributing to this area, proposing new applications (Isento et al., 2011), protocols and algorithms to solve problems related to medium access control (Inoue and Nakagawa, 1994; Stanica et al., 2010), routing (Chennikara-Varghese et al., 2006; Daeinabi et al., 2011) and even security (Qian and Moayeri, 2008), which have been studied and surveyed in different works (Willke et al., 2009; Luo and Hubaux, 2004; Wang et al., 2008; Menouar et al.,).

Although numerous proposals appeared in the different areas, we focused our attention in routing protocols due to the challenging connectivity and mobility problems they have in urban and highway environments. Different proposals have been made considering either urban scenario or highway, such as the one described by Mo et al. (2006) and Karp and Kung (2000), respectively. There are also others that have been made considering both and behave differently depending on the scenario (Okada et al., 2008). In this paper we survey unicast position-based routing protocols regarding their applicability to both scenarios. Unlike other studies that survey the position-based routing protocols with no regard to the scenario (Li and Wang, 2007) or the position-based protocols targeted to the urban scenario (Guoqing et al., 2008), we focused our attention on both urban and highway and we compare both cases.

The remaining of this paper is structured as follows. In Section 2 we differentiate amongst MANET and VANET and we characterise the VANET scenarios. In Section 3 we survey and characterise the different routing protocols and their strategies. Section 4 details position-based protocols. Section 5 compares the routing protocols on each of the scenarios and in Section 6 the we concluded that there is not a protocol suitable for both environments.

2. Scenario

There are significant differences between communications in MANET and VANET. In VANET one can differentiate amongst urban and highway scenario. In this section a characterisation of each of this scenarios will be made.

2.1. MANET and VANET

A MANET can be defined as a wireless network with no previously defined topology where the nodes can move freely, being the topology modified in real-time. In these networks, every node can be considered an end-system or a router, and thus, each one shares its own communication resources with the others, building the network used to transfer the information.

As stated by Meghanathan et al. (2001), VANET are a special case of MANET, being differentiated due to a set of unique properties that characterises the surrounding environment and the nodes. Four major important aspects may be used to characterise them: the scenario, the mobility pattern, the mobility properties and the node properties.

- *Scenario*: In a VANET there is a physical map with streets, roads, avenues, highways, junctions, corners and traffic lights that restrict the freedom of movement of the vehicles. This aspect has a strong impact on the nodes mobility pattern leading to the creation of new mobility models (Harri et al., 2009). On the other hand, buildings, and other sort of obstacles may have a strong impact on the communication, due to inadequate signal propagation conditions (Jochen, 2003).
- *Mobility pattern*: As stated above, vehicles circulate in streets, roads or highways which have pre-determined paths. This means that their movement is not random, but follows a given direction, according to the physical map and road signs. A huge concentration of vehicles may occur at certain places, like crossroads or tolls and a sparse distribution may occur at other places, like unused roads, or highways. In this scenario, irregular connectivity may happen (Viriyasitavat et al., 2001), leading to significant performance degradation caused by collisions in the wireless medium in high density regions, and frequent network fragmentation in sparse density zones (Meireles et al., 2010).
- *Mobility properties*: Vehicles can move very fast when compared with a typical MANET node. This means that, two vehicles can be neighbours at a given instant of time and, due to their speed differences, a short time after that may be out-of-range. Hence, connection time between them can be very short and route maintenance can be hardly supported (Dahiya and Chauhan, 2010).
- *Node properties*: Vehicles must be equipped with a specialised communication device attached or embedded into their body, which have dedicated communication interfaces to connect to

other vehicles or to a fixed infra-structure. This device may interact with on-board sensors, accessing environment information, such as location that can be gathered from the vehicle Global Positioning System (GPS) device (Vehicular ad hoc networks, 2008). On the other hand, the device does not need to have any autonomous power supply system and so no power consumption limitations are foreseen.

According to this, there are two major aspects of VANET that dictate their difference from MANET. The first one is the existence of a complex physical map that restricts the vehicles mobility. In a MANET, the scenario is much simpler, nodes have more freedom to move and hence there is a completely different mobility pattern between the two type of networks. The second one is the related with the mobility nodes: in a VANET they are complex, do not have battery constrains, may have a GPS device, can move very fast, whilst in a MANET the nodes may be much simpler, slower, with battery limitations and probably no GPS device. Hence, the differences are so significant that new protocols and architectures are being developed for VANET environments, such as the ones presented in this paper.

2.2. Urban and highway environment

There is a wide diversity of situations where one can use VANET to communicate, provided that a minimum number of vehicles ensure connectivity. However, when comparing an urban to an highway environment, there are several important differences that have a major impact on the communication paradigm, as stated by Elmar Schoch et al. Behaviour in highway differs from urban environment in the following main aspects:

- *Scenario*: In an urban environment, there are junctions and corners with buildings, affecting the signal propagation. In a highway, as there are no obstacles most of the times a vehicle can forward a message to any other vehicle within the antenna range. Despite this, there have been studies that shown that the vehicles themselves act as obstacles to the propagation (Boban et al., 2001). When many obstacles to the communications are present they can attenuate the radio signal due to a wide variety of phenomena, such as blocking, shadowing, reflection or multi-path propagation, causing significant packet loss (Jochen, 2003).
  Experimental studies have shown that benefits arise when using multi-hop communication, as without it the geometry of the roads, the obstacles and the vehicles' position have a major impact on the communication performance (Wu et al., 2005). Hence, in urban environments multi-hop must be used due to frequent obstacles that make impossible to communicate in a straight line, even when the vehicles are in the coverage area of each other (Lochert et al., 2005).
- *Mobility pattern*: In urban environment there are a lot of streets, avenues and squares located near each other. Thus, a driver has many options to take. For instance, it can make a turn to a different road or it can go straight-ahead. On the other hand, in a highway there are only a few entrances and exits and no crossroads. Thus, most of the time the vehicles can only stay in the same road and there are no sharp turns.
  From a routing perspective, one can select many different options to forward information in a urban environment, whilst, in a highway, most of the times the same set of vehicles may be used to forward information.
- *Mobility properties*: The speed of vehicles is low inside towns and villages, usually limited to 50 km/h, or even lower depending on country legislation, whilst in a highway the limits are about 120 km/h. When the speed is higher the connection time with a vehicle travelling in the opposite direction or a fixed Access Point (AP) decreases significantly. As shown in Jerbi et al. (2007a), the connection time to an AP can be reduced by more than 50% if the speed of the vehicle alters from 50 km/h to 90 km/h: at 90 km/h the connection time with a single hop communication was 66 s, but if the communication uses a vehicle as relay node this time decreases to 25 s.
  Jerbi et al. (2007b) have shown that when vehicles moving in a highway at 90 km/h less than 0.3% of packet losses occurred if one of the communicating vehicle follows the other, but if they are traveling at the opposite direction more than 13% packet losses occurred, leading to a poor network performance. Hence, in highway environments, communication with APs or vehicles circulating in the opposite direction should be avoided.
  Kafsi et al. (2008) have shown that in a urban environment there is a critical density above which connectivity significantly improves. Hence, out of the rush hours when the car density is too low to have neighbours to forward too, if the node sends the packet to a vehicle travelling in the opposite direction of the communication, the message would go further away and probably with no one to send it to as well.
  The speed of a vehicle alters frequently due to speed bumps, traffic lights and crosswalks and so the speed variance is high. Traffic lights have an important impact on connectivity, as the accumulation of vehicles at red traffic lights can be beneficial for connectivity by creating vehicle-to-vehicle meeting points. However, it increases the distance between vehicles which might limit the connectivity as well, as demonstrated in Kafsi et al. (2008).
  In a urban environment people drive slower and at a shorter distance of the front vehicle than they do in a highway, and thus vehicle density should be higher, which alters the average number of neighbours that each node has. This means that each node has more options to select from when there is data to forward. However, since each node sends periodic messages, when the node density is higher the amount of messages sent grows which will cause more collisions, decreasing the packet delivery rate.

2.3. Comparison: urban versus highway

Table 1 summarises the properties of a urban and a highway scenario, illustrating the main differences that have been described in the previous section.

The characteristics of these two environments are so different that the same protocol has very different performance in each of these environments. In fact, Li and Wang (2007) surveyed routing protocols for VANET and showed that some protocols lack efficient support either in a urban environment or in a highway.

Table 1
Scenarios comparison.

Group	Property	Urban	Highway
Scenario	Obstacle	Many	Few
Mobility pattern	Amount of options	Many	Few
Mobility properties	Speed	Low	High
	Speed variance	High	Low
	Node density	High	Low

Guoqing et al. (2008) compare several routing protocols from a qualitative perspective concerning only their use on an urban environment. In Karp and Kung (2000) and Mabiala et al. (2007) several solutions for a highway environment are presented and compared against the authors proposal. Although not having a common base for comparison, from these studies one can conclude that significant differences are foreseen considering routing in urban or highway environment.

3. Routing protocols for VANETs

There are different classification frameworks that have been used to describe routing protocols for VANET. Some authors use as baseline of classification the time at which the route lookup is made (proactive or reactive routing), whilst others differentiate in terms of the information used in forwarding (topology-based or position-based routing). In our paper we use the second approach.

In this section the differences amongst topology based and position-based routing protocols are described and we characterise in detail the position-based strategies and protocols.

3.1. Routing protocols classification

There are two main classes of routing protocols: topology-based and position-based.

- *Topology-based routing* – the IP addresses are used to identify the nodes and setup the routes, using the information about the links that exist in the network to identify the best path to forward data.
- *Position-based routing* – instead of using the IP addresses, position-based routing relies on the knowledge of the geographical position of the nodes to select the best path to forward data to a destination. Thus, when using position-based routing each node must be able to determine its own location and a source node must be aware of the location of the destination node.

Topology-based routing protocols can be reactive or proactive. Some authors (Taleb et al., 2007) refer to a third class, the hybrid class that uses both reactive and proactive concepts.

Reactive protocols only find the path to a destination when a node needs to start a session with that destination and there is no route available. Despite the type of strategy used to build the routing tables and select the paths, reactive routing protocols have two main problems that make them inadequate for VANET. First, there is a significant delay until the communication process is established due to the reactive nature of the protocol. Second, the packet delivery ratio is low when both nodes are far away, because the probability of a broken route increases due to the high mobility of the VANET. Examples of such protocols are the Ad-hoc On-demand Distance Vector (AODV) (Perkins et al., 2003) and the Dynamic Source Routing (DSR) (Johnson and Maltz, 1996).

In the proactive protocols, each node sends periodical information of its routing tables. The routing tables, eventually, tend to have the information of surrounding nodes and knowledge of more than just the one-hop neighbours. This kind of protocols have a significant overhead due to the periodical information transfer and the propagation of routing messages to distant nodes that might probably carry outdated information, since the environment is highly mobile. The work described in Optimised Link-State Routing (OLSR) (Clausen and Jacquet, 2003) and Destination-Sequenced Distance Vector (DSDV) (Perkins and Bhagwat, 1994) are examples of proactive protocols.

As it is shown in the performance evaluation in Khan and Qayyum (2009), neither OLSR nor AODV are able to provide acceptable packet delivery ratio in a VANET scenario despite that OLSR outperforms AODV (Haerri et al., 2006).

Position-based protocols use the position of the destination node to make routing decisions. One of the first position-based routing protocols have been proposed in Takagi and Kleinrock (1984) and is based on the concept of progress to destination. An enhanced solution have been proposed by Finn (1987), at which the selection is based on the geographical distance to the destination node. Instead of using the progress towards the destination as a metric, some authors propose a direction-based approach which uses the angular deviation from the line between the forwarder and the destination (Kranakis et al., 1999). There are also some hybrid strategies between those two have been proposed, like the one described in the Distance Routing Effect Algorithm for Mobility (DREAM) and the one proposed in Dynamic Hybrid Geographic Routing (DHGR) (Chen et al., 2009). Both proposals aims at achieving an adequate tradeoff between performance and energy consumption, which is not a relevant issue in automotive networking.

In the position-based protocols it is assumed that each node has position information available, which is a valid assumption since nowadays most of the cars have a GPS device. For these protocols, the node needs to know the location of the destination, which is done using a location service, such as the Grid Location Service (GLS) (Li et al., 2000), the Reactive Location Service (RLS) (Ksemann et al., 2002) or the Hierarchical Location Service (HLS) (Kiess et al., 2004). From that moment on, the location of the destination is carried in the packet so that the retransmitting nodes do not need to use the location service again, reducing the overhead.

This need for communication with a GPS satellite can be a problem since either of the scenarios can have tunnels but typically they have different characteristics. Normally a tunnel in an highway is made to bypass a mountain and so they are in an almost straight line and so the vehicle position can be predicted with the last known position and the velocity, using a strategy named as dead reckoning. In urban scenarios tunnels are made to bypass heavy traffic zones for those who do not need to go through that zone, thus, urban tunnels can be a complex graph with more than one option to proceed and may not be on a straight line which may make position prediction challenging.

3.2. Position-based strategies

The functionality of a position-based routing protocol may be split in three different aspects: path selection, forwarding and recovery. Different strategies can be used to implement each one of them. The next sections will describe them.

3.2.1. Path selection

In position-based routing it is not mandatory to use a path selection, but one can use a path selection algorithm if it brings an advantage to the routing protocol.

When no road path is selected data packets are forwarded to one of the neighbour nodes without taking into account the road conditions using the forwarding strategy of the protocol (Karp and Kung, 2000; Lochert et al., 2005; Rao et al., 2008). Since no additional information is needed in the data packets to implement it, the overhead does not increase when using the *no path* strategy. However, the possibility of leading the message to paths that have no availability is high, especially on urban scenarios because one does not know the node density when selecting the next hop.

Two of the most commonly used path selection strategies are presented bellow.

One commonly used path selection strategy is the based on the well known Dijkstra algorithm, in which a path between a pair of nodes (source, destination) is computed at the source node, with the junctions and intersections as the graph edges. We named it as *full path using Dijkstra*. When using this strategy, each packet carries the position of all junctions to be traversed. Different metrics can be used to compute the cost of the paths. Some routing solutions consider that the cost of each road is the distance (Lochert et al., 2003), whilst others use more attributes to weight the cost. This is the case of Seet et al. (2004), that uses the information of the number of bus lines to weight the paths.

Thus, as depicted in Fig. 1, when the source node *S* wants to communicate with the destination node *D*, there are two available paths: the green that crosses junctions *J*1, *J*2, and *J*4 and the red that crosses junctions *J*1 and *J*3. If the metric used is the distance, the path will be {*J*1, *J*3, *D*}, represented by the red line, as it is the shortest one. However, if the traffic is also taken into account, the path would be {*J*1, *J*2, *J*4, *D*}, represented by the green line, as it has more vehicle to forward data. In both cases, each of the packets sent by the source node will carry that path information.

Full path using Dijkstra strategy has two main problems: overhead and reduced availability. It has a big overhead since each packet needs to carry information about the entire path (the various junctions it traverse). It also has reduced availability due to many disconnection problems that might happen, since the path selection does not take into account neither the number of retransmitting vehicles nor the vehicles mobility. Thus, one may select a path that does not have enough vehicles to guarantee the connectivity. Or, even if the number of vehicles was taken into account, by the time the packet arrives at a given road segment, all the cars could be long gone.

Other used approach is to select, at each junction, which road to follow next (Lochert et al., 2005; Jerbi et al., 2007c). We named it as *next junction selection*. Thus, each time a packet arrives at a junction the node who carries it selects which of the surrounding roads is the best to follow and selects a node that uses that road. This can be done using different metrics, the most commonly used is a combination between the progress toward the destination and the vehicle density of that road. Each of the metrics can have a different weight as suggested by Jerbi et al. (2007c). The weight of each metric can be set depending on what is more important.

In the example of Fig. 1 the path, first selected at the source node *S*, determines *J*1 as the next junction. When the node carrying the packet arrives at junction *J*1, it would select the next junction. If the node density is still the same of Fig. 1, *J*2 would be selected as next junction and, by the same process, at junction *J*2 the next junction chosen would be *J*4. At each moment the packet would only carry two positions: the position of the destination and the position of the next junction.

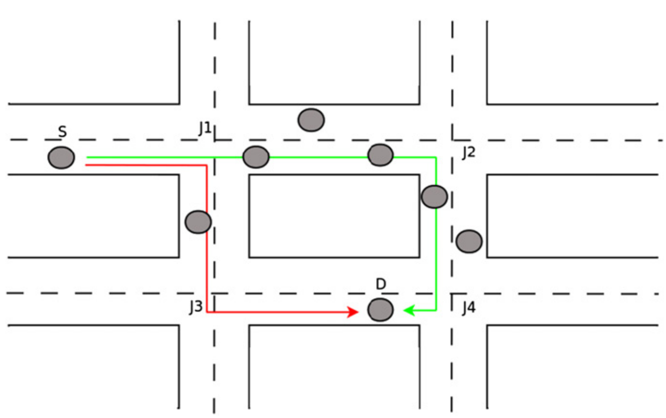

Fig. 1. Path selection. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

This solution does not increases the overhead as much as the full path using Dijkstra since only one location (the next junction) is needed beside the position of the destination. Additionally, as path selection is performed hop-by-hop, at each junction there is a smaller probability of disconnection as routing decisions are postponed and when they are taken the node has an updated view of the neighbourhood conditions and thus an higher availability is expected. When the metric used is the density the availability is even higher since a road with few vehicles would not be selected.

3.2.2. Forwarding strategies

In spite of having a path selected or not, every position-based routing protocol needs a forwarding strategy either to forward to the destination or to forward between junctions in the selected path. Some of the most used approaches are presented in this section.

The simplest, but yet effective, forwarding solution is the *greedy forwarding*, which is used by Karp and Kung (2000). In this approach the sending node sends the packet to the neighbour that is closer to the destination. This can be done since the Hello messages carry the node position, and in position-based routing the position of the destination is in the packet header. In spite of its simplicity, greedy forwarding may lead to an inadequate selection of nodes, as being the closest node to destination does not mean it reaches the destination or that it is the best route to it.

When any type of path is used, one can use what is normally referred to as *greedy along the path*, which, as the name suggests, is the greedy approach but considering only the nodes that are on the selected path or road to next junction. This is the approach used by Jerbi et al. (2007c). Although improving the basic greedy forwarding, it still may cause an inadequate selection of the forwarding node, due to an underestimation of the physical conditions (propagation and nodes mobility).

There are also a couple of greedy approaches with some restrictions (Lochert et al., 2005), that have been created to overcome such problems. Some of them (Jerbi et al., 2007c) are meant to mitigate the propagation problems in junctions, once a communication can not traverse a corner because of the obstacles and buildings. They are based on the existence of a priority node in the centre of the junction: if such node is a neighbour of the sending node, the latter would always send data to that priority node. If vehicles move very slow or do not move at all, the vehicle in the centre of a junction remains the same and receives all the incoming traffic. Hence, it may become a communication bottleneck. This approach was called *Restricted greedy*.

Other restriction is to forward the packet only to the neighbours that are moving toward the destination, or toward the next junction if there is a path selected. This approach can still lead to errors such as choosing a next junction from which the other adjacent roads have no vehicles and the packet has to travel back on the same road, but the errors happen with less frequency than with other approaches. This approach is referred to as *Improved greedy*.

In greedy forwarding when the vehicles are waiting on a red light they might have the tendency to send the packet to vehicles traveling in the opposite lane, since improved greedy only routes packets through vehicles traveling towards the destination this problem will not occur.

3.2.3. Recovery-mode strategies

Greedy forwarding strategies can run into a situation called *local maximum*, or *local optimum* as some authors refer, in which the sending vehicle is closer to the destination than all of its neighbours and the destination is not reachable by one hop. However, this does not mean that there is no connectivity to the destination and when a local maximum occurs a recovery strategy is used. Some of the most relevant recovery strategies are described in this section.

One of the recovery-mode strategies widely used is the *right-hand rule* to traverse graphs. The rule says that if node n receives the packet from edge E_1, it sends the packet through its next edge counterclockwise about n. The routing protocol switches back to forwarding mode once the forwarding node is closer to the destination than the node that triggers the recovery strategy. To use the right hand rule we must have a planar graph by Karp and Kung (2000), who use Relative Neighbourhood Graph (RNG) computed at each node in order to planarize the graph by removing edges that cross. Since in VANETs the network nodes are constantly moving and at high speeds, this can lead to loops in the right-hand rule approach.

The example of Fig. 2 represents this situation, at node S the protocol would enter in recovery-mode, as it does not have any neighbour closer to the destination and at node Y it would change back to forwarding mode, as it is closer to node D than S.

Other approach used is the *carry-and-forward* (Li et al., 2000). As the name suggests, when the local maximum occurs the node carries the packet until a eligible neighbour appears. This approach leads to bigger delays.

Instead of using a recovery strategy, some algorithms recalculate the path when the local maximum occur (Seet et al., 2004), which can lead to higher delays and to a bigger number of hops.

3.3. Comparison

In the previous sections different approaches for each one of the position-based routing strategies have been described. In this section we summarise them and evaluate their performance characteristics, considering the following metrics:

- *Overhead* – that represents the amount of control information needed to support the strategy.

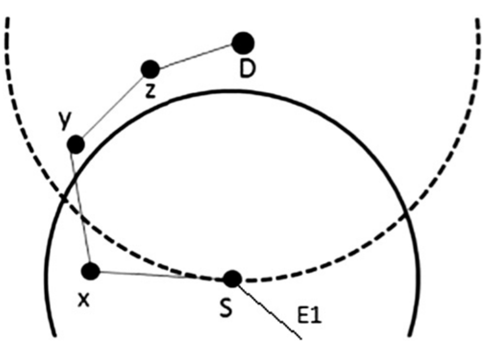

Fig. 2. Local maximum situation.

- *Availability* – that states the amount of time the VANET is usable and assesses whether or not there are connectivity problems that are not properly addressed by the strategy.
- *Resilience* – that indicates if bottlenecks are introduced by the strategy.
- *Latency* – that represents the amount of time needed to transmit data from the source to the destination when a particular strategy is used.

Table 2 summarises our evaluation. When no score is given (which is represent by a dash, –), we mean that the parameter under evaluation is not relevant for the strategy under consideration. The scores vary amongst *High*, *Medium*, *Low* and *None*. These scores are not absolute values, they are *high*, *medium* or *low* in comparison to the other approaches. When there is a score that depends on several external conditions we score the parameter with the possible options and we qualify it, by describing on what does the variation depends.

The path selection strategy can influence the overhead, availability and latency. The full path selection is the worst option, as it has high overhead, low availability and medium latency. The overhead is due to the fact that the entire path is inserted in the packets at the source node. The more complex the path the bigger the overhead is. Connectivity fails either because the network density was not taken into account to define the path or the vehicles in the path have moved and become out of range, leading to frequent path recalculations and hence the availability is low. Concerning the latency, one can considers it as medium because every time a path is recalculated the packets need to be forward back through a different path. One can not perform an easy choice of the other two strategies, as they have different drawbacks. The no path strategy has zero overhead because no information is carried on the packets, whilst the next junction selection has some overhead due to the insertion of the next junction in the packet. The next junction strategy has a variable availability, between medium and high, depending if the used metric is only the distance or the vehicle density as well, since the probability of reaching a local-maximum is lower if we calculate the next junction taking into account node density in each road. For similar reasons, the no path selection strategy has a low availability, since the vehicle density is not used as well. When using no path selection there is a medium latency, since the vehicle density is not taken into account and the probability of going towards a local-maximum can be high in more sparse regions. Regarding the next junction strategy, it has a low or medium latency depending on the metric being the distance and the vehicle density or being only the distance since this alters the probability of getting into a local-maximum situation.

In the forwarding strategies the overhead is low except on greedy along the path, as it requires the insertion of the path in the packet to operate. The other forwarding strategies have low

Table 2
Performance comparison of the strategies.

Protocol phase	Strategy	Overhead	Availability	Resilience	Latency
Path Selection	No path selection	None	Low	—	Medium
	Full path using Dijkstra	High	Low	—	Medium
	Next junction	Low	Medium or High (metric)	—	Low or Medium (metric)
Forwarding	Greedy forwarding	Low	Unknown	High	Low
	Greedy along the path	Low or High (path)	Unknown	High	Low
	Restricted greedy	Low	Unknown	Low	Medium
	Improved greedy	Low	Unknown	Low	Medium
Recovery	Right-hand rule	Low	Unknown	—	Medium
	Carry-and-forward	None	High	—	High
	Path recalculation	None	Low	—	Unknown

overhead since the only information needed is the position of the destination. If the path selection used is next junction, the overhead is low but if full path is used then the overhead is high. Since only restricted and improved greedy strategies have special nodes (coordinators or APs), they are the only who have low resilience whilst the other strategies have no bottleneck issues. In terms of availability, one can not be certain how the different strategies would relate to each other, therefore they were marked as unknown. In terms of latency introduced by the strategy, the restricted and improved greedy have a bigger value since both of them might have an extra hop for each junction traversed (coordinator node or AP). Additionally, the data traffic concentration in these nodes might introduce additional delays. Thus, the most adequate forwarding strategies seem to be the greedy forwarding or the greedy along the path if the path selection strategy used is the next junction.

The recovery-mode can influence the overhead, availability and latency. In terms of overhead, the right-hand rule does not contributes much since the only information added is the distance at which the packet entered recovery-mode, the carry-and-forward does not have overhead since it keeps the packet and the path recalculation strategy has no overhead as well since it computes the path locally with the GPS information. In terms of availability, in the right-hand rule it is unknown once it depends on nodes available and their disposition in the physical map. Carry-and-forward never suffers from disconnection because it keeps the packet and needs no neighbour making it always available. The path recalculation has low availability because it uses a complete path which is shown in the path selection row of the table that has low availability. As to latency, carry-and-forward has an high impact once the speed of the vehicle is much lower than the signal propagation speed of a wireless transmission. Since the right-hand rule does not have this issue, its latency is lower than carry-and-forward latency but it is not low once the packet can go around the block, so it travels a longer path. In the path recalculation it is hard to predict the latency since it depends on the path calculated by the path selection strategy. As shown by Wellens et al. (2007) the vehicle speed has little influence on performance up to 180 km/h.

4. Position-based routing protocols

The different combinations of the above mentioned strategies lead to the existence of several position-based routing protocols. This solution is the base of the current position-based protocols that are being used in VANETs. In all of them, the sending node first uses a location service in order to find the geographic position of the destination node. This location service can be either reactive or proactive. The next sections will describe the most relevant routing protocols.

4.1. GSR

The Geographic Source Routing (GSR) (Lochert et al., 2003) chooses a road path to the destination using Dijkstra shortest path algorithm with the GPS map information. This path consists of a set of junctions that need to be transversed to reach the destination. As no real-time traffic information is used, this calculation is made disregarding the amount of vehicles in each of the roads. GSR selects vehicles to forward data to the next junction and repeats this process until the destination node is reached using the greedy strategy along the path. When there is no vehicle available in the selected road, it tries to select another vehicle outside that road using greedy forwarding instead of using one of the described recovery strategies. In their tests, Ksemann et al. (2002) used RLS as location service.

The pseudo-code of GSR can be seen in Algorithm 1, in which we considered:

- *D* – the destination node.
- *p* – the receiving packet.
- *R* – the node receiving a packet *p* for destination *D*.
- *N* – the set of one-hop neighbours of *R*.
- *n* – a node of the set *N* that is used to forward the packet *p*.
- Path – the set of junctions of the road path to the destination node *D*.
- *J* – the next junction.

Algorithm 1. GSR pseudo-code.

```
if R=source S of p then
  Initialise Path=NULL
end if
while p not sent do
  {Full path using Dijkstra}
  if Path=NULL then
    Set Path=Weighted_Path_Dijkstra (R, D)
    if Path=NULL then
      {No Path exists}
      Discard(p)
      Return
    end if
  end if
  {Select the next hop according to greedy along the path}
  if ∃ n ∈ N: Distance (n, J) ≤ Distance (R, J) then
    Forward (p, n)
  else
    {Local-maximum occurs, use simple greedy}
    if ∃ n ∈ N: Distance (n, D) ≤ Distance (R, D) then
      nextHop=Min_Distance(N, D)
      Forward (p, nextHop)
      Return
    else
      Discard(p)
      Return
    end if
  end if
end while
```

4.2. A-STAR

The Anchor-based Street Traffic Aware Routing (A-STAR) (Seet et al., 2004) relies on the calculation of a full path to forward data although using a different approach than GSR. In A-STAR the sending node calculates the road path (Anchor Path) by a Dijkstra shortest path weighted by the number of bus lines that pass through each road. The forwarding strategy is greedy along the path. If a local-maximum occurs, the node marks the road as "out-of-service" and recalculates a new road path to destination from the current position. The authors did not mentioned the location service used.

The pseudo-code of A-STAR is represented in Algorithm 2 with:

- AnP – the Anchor Path to destination.
- *L* – the number of nodes packet *p* has traversed.
- L_{max} – the maximum number of nodes packet *p* is allowed to traverse.
- LR – the number of times packet *p* has been recovered.
- LR_{max} – the maximum number times packet *p* is allowed be recovered.

Algorithm 2. A-STAR pseudo-code.

```
if R=source S of p then
  Initialise AnP=NULL
else
  if L ≥ L_max or LR ≥ LR_max then
    Discard (p)
    Return
  end if
end if
if Has_Out_of_Service(p) then
  Update_Out_of_service(Street_In_Header)
end if
while p not sent do
  if AnP=NULL then
    {AnP initialisation through full path using Dijkstra}
    Set AnP=Weighted_Path_Dijkstra (R, D)
    if AnP=NULL then
      {No anchor path exists}
      Discard (p)
      Return
    end if
  end if {Forward using greedy along the path}
  if ∃ n ∈ N: Distance (n, D) ≤ Distance (R, D) && n ⊂ AnP
then
    nextHop=Min_Distance(N \{n ⊄ AnP}, D)
    Forward (p, nextHop)
    Return
  else
    {Local-maximum occurs, recalculate path}
    Update_Out_of_service(Current_Street)
    Append_Header(p, Current_Street)
    Set AnP=NULL
  end if
end while
```

4.3. GPSR

Greedy Perimeter Stateless Routing (GPSR) (Karp and Kung, 2000) does not calculate any path from source to destination. With GPSR each forwarding node inserts the destination position in the packet header and sends the packet its one-hop neighbour that is closer to the destination node, using the greedy forwarding strategy. When none of the neighbours is closer to the destination than the node itself, the node enter the recovery-mode, called perimeter mode, which uses the right-hand rule. GPSR return to greedy forwarding when the node having the packet is closer to the destination then when it entered recovery-mode.

GPSR algorithm is represented through pseudo-code in Algorithm 3.

Algorithm 3. GPSR pseudo-code.

```
if ∃ n ∈ N: Distance (n, D) ≤ Distance (R, D) then
  {Greedy forwarding}
  nextHop=Min_Distance(N, D)
  Forward (p, nextHop)
  Return
else
  {Local-maximum occurs, use right-hand rule}
  nextHop=Right_Hand_Rule(N)
  Forward (p, nextHop)
  Return
end if
```

4.4. GPCR

The Greedy Perimeter Coordinator Routing (GPCR) (Lochert et al., 2005) solves the problem caused by the obstacles in the junctions by considering vehicles in the middle of the junctions as special nodes, called coordinators. Similarly to GPSR, the GPCR do not calculate a path from source to destination either it uses the greedy forwarding strategy with one modification: if a coordinator is an one-hop neighbour, it is chosen independently of his proximity to the destination. Coordinators are distinguished from other vehicles by a flag in the periodic hello message. The recovery mode adopted was the right-hand rule. No location service was mentioned by Lochert et al. (2005).

The pseudo-code of GPCR can be seen in Algorithm 4.

Algorithm 4. GPCR pseudo-code.

```
if ∃ n ∈ N: Is_Coordinator (n) && Distance (n, D) ≤ Distance
  (R, D) then
  {Restricted greedy}
  Forward (p, n)
else
  if ∃ n ∈ N: Distance (n, D) ≤ Distance (R, D) then
    nextHop=Min_Distance(N, D)
    Forward (p, nextHop)
    Return
  else
    {Local-maximum occurs, use right-hand rule}
    nextHop=Right_Hand_Rule(N)
    Forward (p, nextHop)
    Return
  end if
end if
```

4.5. GyTAR

Improved Greedy Traffic Aware Routing (GyTAR) (Jerbi et al., 2007c) protocol uses fixed wireless routers in junctions to increase connectivity. In this protocol no path from source to destination is constructed. In each junction the fixed node calculates which is the best next junction taking into account the number of vehicles between them and the progress towards the destination in terms of distance (also referred as curvemetric distance[1]).

Let us consider a source node S, a destination node D and a current junction I. A junction J is chosen as the next candidate junction if it has the highest score based on the formula:

$$score(J) = \alpha[1-D_p]+\beta\left[\min\left(\frac{N_{avg}}{N_{con}},1\right)\right] \wedge \alpha+\beta=1 \tag{1}$$

where

- α and β are weights for the distance and the vehicular density, respectively.
- D_p is the progress toward the destination.
- N_{avg} is the average number of vehicles per cell.[2]
- N_{con} is a constant which represents the ideal connection degree to have within a cell.

As proposed by Okada et al. (2009), a new link metric is used: the progress toward the destination, which is given by:

$$Dp = \frac{D_j}{D_i} \tag{2}$$

[1] Distance measured along a path.
[2] The cell is determined based on the wireless transmission range of vehicles.

where:

- D_j is the curvemetric distance from J to the destination.
- D_i is the curvemetric distance from I to the destination.

And, the average vehicles per cell is given by:

$$N_{avg} = \frac{N_v}{N_c} \quad (3)$$

where:

- N_v is the number of vehicles between I and J.
- N_c is the number of cells between I and J.

Between junctions an improved greedy forwarding is used: the node that has the packet to send, forwards it to the neighbour that is closer to the destination junction amongst the neighbours that are moving toward the destination. If one of the neighbours is the destination junction, the node sends the packet to it despite the location of the neighbours. As recovery-mode GyTAR uses the carry-and-forward method. Li et al. (2000) selected GLS as the location service. Pseudo-code of a GyTAR node is represented in Algorithm 5.

Algorithm 5. GyTAR pseudo-code of an mobile node.

if R is AP **then**
  J=Choose_Next_Junction()
end if
if ∃ n ∈ N: n = J **then**
  {*Improved greedy*}
  Forward (p, n)
  Return
else
  if ∃ n ∈ N: Distance (n, J) ≤ Distance (R, J) && Is_Moving_Towards (n, J) **then**
    nextHop=Min_Distance_Same_Direction(N, J)
    Forward (p, nextHop)
    Return
  else
    {*Local-maximum occurs, use carry-and-forward*}
    Wait_For_Neighbours()
  end if
end if

4.6. GPSR-L

In GPSR with Lifetime (GPSR-L), Rao et al. (2008) recognise that the different speeds amongst the vehicles makes it likely for a vehicle to receive a HELLO message from a node that leaves its transmission range before anything can be sent. On the other hand, a HELLO message can be lost and the forwarding node may wrongly assume that the neighbour is not there anymore. To solve those problems the concept of lifetime is introduced. The lifetime is calculated using the difference of distances between the nodes computed with the information of two consecutive HELLO messages. The algorithm of GPSR-L is the same as the one presented in Algorithm 3 but the set N only contains the nodes that have a valid lifetime.

4.6.1. MOPR

In MOvement Prediction-based Routing (MOPR) the authors propose a add-on to other routing protocols like GPSR (Menouar et al., 2007) and AODV (Menouar et al., 2006) rather than a routing protocol by itself. MOPR chooses a path in terms of communication lifetime which is calculated by the speeds of the two neighbouring vehicles. MOPR calculates the Link Stability (LS) for each neighbour which is a relation between the lifetime and σ (a constant value to represent the route validity time). LS is calculated as represented in the following equation:

$$LS[i,j] = \frac{LifeTime[i,j]}{\sigma} \quad (4)$$

If $LifeTime[i,j] \geq \sigma$ then we will have that $LS[i,j] \geq 1$

When the underlying routing protocol has to calculate the next hop amongst its neighbours it will only take in consideration those that have $LS[i,j] \geq 1$. Like GPSR-L the pseudo-code proposed in Menouar et al. (2007) in which the underlying protocol is GPSR can be seen in Algorithm 3, but the set N only contains the nodes that have a valid lifetime and therefor a $LS[i,j] \geq 1$.

4.7. Comparison

In the previous section the most relevant position-based routing protocols were described. Table 3 summarises the information about them. If no path strategy is used the metric for path selection field is not applicable and thus marked as "N/a". When a certain propriety is not used in the routing algorithm it is marked as "Not used".

Table 3
Protocols comparison.

Group	Property	GSR	A-STAR	GPSR	GPCR	GyTAR	GPSR-L	MOPR
Scenario	Obstacles awareness	Not aware	Not aware	Not aware	Aware	Aware	Not aware	Not aware
	Street awareness	Aware	Aware	Not aware	Aware	Aware	Not aware	Not aware
Architecture	Infrastructure	None	None	None	None	In junctions	None	None
	Bottleneck	None	None	None	Coordinator	AP	None	None
Path	Strategy	Full path	Full path	No path	No path	Next junction	No path	No path
	Metrics	Distance	Distance and bus lines	N/a	N/a	Progression and vehicle density	N/a	N/a
Forward	Strategy	Greedy along the path	Greedy along the path	Greedy	Restricted greedy	Improved greedy	Greedy	Greedy
	Neighbour lifetime	Not used	Not used	Not used	Not used	Not used	Successive Hellos	Successive Hellos
	Neighbour direction	Not aware	Not aware	Not aware	Not aware	Aware	Not aware	Not Aware
Recovery	Strategy	Greedy	Recalculate path	Right-hand rule	Right-hand rule	Carry-and-forward	Right-hand rule	Right-hand rule

The group of attributes considered were:

- *Scenario* – the way the protocol deals with the specifications of the physical map, like streets or obstacles.
- *Architecture* – the specific elements the protocols uses, such as a physical infrastructure, or the limitations caused by the protocol architecture.
- *Path* – the strategy and metrics used to built a path, if path selection is made.
- *Forwarding* – the strategy and some specific information that might be used to forward data, such as the neighbours lifetime or the movement direction.
- *Recovery* – the strategy used to recover from local maximum.

The presented protocols have different ways of dealing with VANET scenarios in respect to obstacles and street awareness. GPCR and GyTAR are the only protocols that take into account both obstacles and streets, GPSR, GPSR-L and MOPR do not have neither obstacles nor streets awareness. GSR and A-STAR are street aware but do not take obstacles into consideration.

In the network architecture only GyTAR uses infrastructures. Only protocols with priority nodes have bottlenecks. Hence, both GPCR and GyTAR have bottlenecks by the means of the coordinator or the AP.

Relatively to the strategies they use different combinations and each of them affects the performance in different ways as it is shown in Table 2.

To understand the performance of each algorithm it is necessary to understand how each of them behaves in different environments.

5. Evaluation

As stated in Section 2.3, vehicles mobility have many differences in highway and urban scenarios and these differences have a significant impact in the routing protocol performance. In this section we identify, for each scenario, how each of their properties demand for the routing protocol properties and evaluate the adaptability of the routing protocol to the scenarios.

5.1. Routing in an urban environment

The properties that best characterise the urban environment are

- *Obstacles* – due to the high number of obstacles that might exist, an adequate routing protocol must be aware of them and provide mechanisms to go around them. Should the routing protocol not take this into account and transmission problems occur which might increase the latency or reduce the availability due to packet loss. Jerbi et al. (2007a) have shown that obstacles in a city environment lead to a pathloss of about 26db and that more than 6% of the packets may be lost in some situations Thus, for an urban environment, the routing protocol should have street and obstacle awareness.

  The use of an infra-structured network with APs located in junctions and corners may overcome this problem, as the APs will be used to forward packets in these places.

  On the other hand, the choice of the path selection and recovery strategies may also have an impact on this. The forwarding strategy must take into account the physical map which lead to the use of the restricted or the improved greedy strategies. Concerning the recovery strategy either the right-hand-rule or the carry-and-forward might be useful, as there is no clear advantage of sending the packet to another node, selected with no optimised criteria, over transporting it.
- *Amount of options* – due to the characteristics of the physical map, drivers can make abrupt turns and become out of range of each other. Therefore, the amount of time each node stays in the neighbourhood is not predictable.

  Thus, the routing protocol does not need to have a very complex mechanism to maintain the nodes neighbourhood updated, as probably the information stored would be outdated. Hence, the protocol would not have a significant gain by using lifetime.
- *Speed* – due to the low speed of the vehicles, they can communicate with some fixed node for a sufficient long time. According to the experiment described by Jerbi et al. (2007a) connectivity time last for more than 143 s, for a speed of 50 km/h . Thus, it is possible to use an infrastructure, as the connectivity time is long enough to enable the communication with the AP.

  As stated before, the use of APs seems an adequate solution to overcome the obstacle problems. However, as they are the central point of communication in their neighbourhood the APs introduce bottlenecks. In roads where the traffic intensity is very high, or when the vehicles are stopped in a junction, the number of vehicles accessing the AP may also be very high leading to more frequent collisions in the wireless medium which in turn leads to a reduced availability or an high latency. Thus, if one intends to use the network in city centres, where the vehicles density is high, bottlenecks are a major issue to consider and thus the use of AP should be avoided.
- *Speed variance* – due to the characteristics of the physical map there are high speed variances and so nodes neighbourhood is not predictable. Hence, there is no need to use lifetime because the prediction made would probably be inaccurate.
- *Node density* – the vehicle density is usually high in a urban environment, restricting significantly the performance of the network, as more data sessions might exist, more nodes might share the same collision domain and exist between a pair of end-points. Therefore, routing overhead increases significantly and so a low overhead routing protocol must be used. Thus, according to Section 3.3 , a protocol that uses the full path selection should not be used.

Hence, in a urban environment the routing protocols must be aware of the obstacles, have no bottlenecks, do not use lifetime in the forwarding and do not use the full path selection strategy. Table 4 summarises the characteristics of the routing protocols concerning these properties.

5.2. Routing in an highway environment

The analysis made in the previous section applied on an highway environment lead to the following set of properties:

- *Obstacles* – as they are almost always absent in an highway, routing protocols may ignore them. Thus, most of the times

Table 4
Protocols comparison in urban scenario.

Property	GSR	A-STAR	GPSR	GPCR	GyTAR	GPSR-L	MOPR
Obstacles awareness	×	×	×	√	√	×	×
Street awareness	√	√	×	√	√	×	×
No bottleneck	√	√	√	×	×	√	√
No full path selection	×	×	√	√	√	√	√

the propagation conditions are good enough to allow the communication with neighbour nodes.

- *Amount of options* – due to the characteristics of the physical map, drivers can make few turns and thus one can predict the amount of time two nodes are neighbours. Thus, maintaining the list of neighbour nodes updated is an useful way of increasing the chances of forwarding packets to the most adequate nodes. Hence, lifetime is an useful mechanism to predict which vehicles will remain in the neighbourhood in a near future and will be good candidates to forward data.
- *Speed* – most of the times, vehicles circulate with high speed.This fact, has two major impact on the routing protocol characteristics. First, no fixed wireless APs can be used as connectivity time is too short. Second, a vehicle should only use vehicles travelling in the same direction as data to forward the packets.

  In case of accident or congestion, the speed will be very low or even zero. Thus, each one of the vehicles is able to communicate with the APs, as connectivity time is not an issue. However, as most of the drivers or passenger might try to communicate the abnormal road condition, the communication with the AP will introduce a significant bottleneck. In such case, the highway scenario becomes similar to the urban.
- *Speed variance* – since in highway the vehicle velocity is typically the same for long periods of time, vehicles can be neighbour during a long time. Once again, as one can predict the nodes neighbourhood the use of lifetime will enhance the communications.
- *Node density* – most of the times, the nodes density is low and hence the impact of the overhead is also low. Thus, from this perspective the use of a full path computation is not a big impairment to the performance in the highway scenario, as there is a reduced number of junctions.

  On other hand, recovery situations might happen very often, when the vehicles density is very low, for instance during the night or in less used highways. The use of the carry-and-forward strategy is the most adequate option, as selecting a node based on the right-hand-rule might lead to the choice of a node that goes in the opposite direction.

Thus, in a highway environment, routing protocols should use no infrastructure but should take into account the neighbours direction and should use the concept of lifetime. Table 5 summarises the characteristics of the routing protocols concerning these highway properties.

5.3. Comparison

The analysis of Tables 4 and 5 shows that there is no routing protocol that performs best in both environments.

GyTAR and GPCR are the only two protocols that have obstacles awareness. Both of them have also street awareness and do not use the full path selection. However, they have as common drawback the bottleneck. On the other hand, GSR, A-STAR, GPSR, GPSR-L and MOPR do not introduce any bottleneck. GSR and A-STAR are also aware of the streets, but use the full path strategy, whilst GPSR, GPSR-L and MOPR are not aware but do not use this strategy. Thus, there are two good candidates for the urban environment, GPCR and GyTAR.

Table 5
Protocols comparison in highway scenario.

Property	GSR	A-STAR	GPSR	GPCR	GyTAR	GPSR-L	MOPR
No infrastructure	√	√	√	√	×	√	√
Neighbour direction (same)	×	×	×	×	√	√	√
Lifetime	×	×	×	×	×	√	√
Carry-and-forward	×	×	×	×	√	×	×

To solve the obstacle problem in the junctions, GPCR depends on having a neighbour in the middle of the junction when needed. If this is not the case, GPCR is not able to deal with obstacles, as all nodes have similar conditions. GyTAR solves this problem using an AP at the junction, meaning that there is always a node in the junction when needed. GPCR coordinators and APs of GyTAR introduce bottleneck since all nearby communications will pass through them. Nevertheless, the situation is more critical in GyTAR, as in GPCR different nodes will assume the role of coordinator due to their movements.

Although GyTAR provides a more complex solution for selecting the next junction, that takes into the progression of the different junctions towards the destination and the vehicles density of each junction. However, as it does not take into account the vehicles direction inadequate options may be made, since it is possible to choose a junction in which all vehicles that are between it and the current junction come in the opposite direction and will be useless to the forwarding vehicle. Even so the probability of choosing a road with no forwarding vehicles is lower than of GPCR due to the computation of the vehicles density performed by the APs.

Therefore, both protocols have their drawbacks and thus one can select each one of them. When choosing between these two protocols, one needs to setup the tradeoff between the performance that might be achieved by the GPCR the protocol and the investment made in terms of infrastructure to use GyTAR.

Concerning the highway, the most adequate option is either GPSR-L or MOPR, which fulfill all the requirements previously mentioned, except the use of the carry-and-forward recovery strategy. GyTAR seems to be the second best choice, as it only selects the neighbour of the same direction and it uses the carry-and-forward as recovery strategy.

The rest of the protocols have very similar characteristics, sharing an important feature which is the lack of infra-structure. If small changes can be considered to them, most of the required properties can be integrated: the concept of lifetime can be easily implemented, as well as the packet forwarding to nodes in the same direction and the use of the carry-and-forward strategy. Therefore, all of them could be a good candidate for use in a highway, except for GyTAR that needs to use infrastructures.

6. Conclusion

In this work a qualitative survey of position-based routing protocols was made with consideration to the different environments. The major goal was to identify weather there is a good candidate for both environments or not.

A differentiation of the environment characteristics was made and we found that urban and highway environments have different characteristics regarding the scenario, the mobility pattern and the mobility properties.

The survey of the position-based routing approaches started by the study of the different strategies that might be used and the qualitative assessment of their performance. Based on it, one can conclude that next junction is the most adequate selection strategy due to the low overhead has the best availability. With the exception of the greedy along the path forwarding strategy, all the others have a low overhead, but the greedy strategy offers an highest resilient solution when compared to the restricted or improved greedy due to the bottlenecks they introduce.

Concerning the recovery strategies the available options have complementary advantages regarding overhead and the latency.

Several position-based routing protocols have been described, comprising different and relevant approaches, such as GSR, A-STAR, GPSR, GPCR, GyTAR, GPSR-L and MOPR. After a qualitative comparison and an identification of the most important requirements of the two environments, we conclude that there is not a protocol adequate for both urban and highway environments. The best option for the urban case is to use GPCR or GyTAR, whilst for the highway GPSR-L and MOPR fulfill most of the requirements and GyTAR is the less adequate.

Using different protocols for the different scenarios might not be a good option, specially if communications between both environments are foreseen since it is not easy to define when to make the transition between the two protocols. In the case of transition from highway to urban scenario, if the protocol transition is made too soon and the vehicle still had packets to forward to other vehicles in the highway, it would not be able to do it since those nodes are using a different routing protocol. If the protocol transition was made too late the vehicle could loose connectivity unnecessarily since the neighbours node are using a different protocol. The same would happen in a transition from urban to highway. Therefore, a new type of hybrid protocol must be designed aimed to adapt itself to the type of environment and that solves the protocol transition issue.

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