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PSCAR : A Proactive-optimal-path Selection with Coordinator Agents Assisted Routing for Vehicular Ad hoc NETWORKS

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Abstract

In this paper, we propose the Proactive-optimal-path Selection with Coordinator Agents Assisted Routing (PSCAR) protocol for Vehicular Ad hoc NETWORKS (VANETs) in an urban environment. The main idea of PSCAR is to contribute static nodes as Coordinator Agents placed at each intersection¹, in order to improve the routing performance and to deal with radio obstacles (buildings, trees...) and voids as encountered in urban environments. Since the Coordinator Agents are static nodes, each one knows all the paths to any other Coordinator Agent in the network. Thus, instead of searching an optimal path toward the destination node, PSCAR will determine an optimal path to the nearest Coordinator Agent to the destination node so as to better anticipate any change of the destination's position. The optimal path is selected according to two criteria: the total physical distance and the vehicle density on the path. The vehicle density is estimated based on a fundamental diagram of the traffic that allows estimating the vehicular traffic density on each road segment. To evaluate the performance of PSCAR we used the Network Simulator 2 (ns-2) and the mobility simulator SUMO. We compare our scheme with some existing solutions at the aim of showing its effectiveness, in terms of packet delivery ratio, end-to-end delay, and network overhead.

Keywords

Vehicular Ad hoc NETWORKS; Position-based routing; Greedy forwarding; Carry and Forward; Radio obstacles; Urban environments; Traffic density; ns-2; SUMO.

¹ An intersection is a place where two or more roads join or meet.

1. Introduction

With the rapid evolution of wireless communication technologies, a new kind of Mobile Ad hoc NETWORKS (MANETs) called Vehicular Ad hoc NETWORKS (VANETs) appeared where the nodes are vehicles and which do not move randomly but follow a particular mobility pattern (Pu et al., 2015). This mobility is relatively predictable because it is restricted to the vehicles' roads.

VANETs have several properties which distinguish them from MANETs. The most important one is the high mobility of the nodes which induces frequent changes in the network topology. This means that the probability of network partitions is high and the end-to-end connectivity is not always guaranteed. In addition, the distribution of the vehicles in the network is often non uniform where different segments have sparse vehicles' traffic and some other segments may have very dense vehicles' traffic.

These networks fascinate and attract a great interest of the scientific community due to their promising application areas (Hechri et al., 2015). They allow, by using the wireless technology, a vehicle-to-vehicle (V2V) communication and a vehicle-to-infrastructure (V2I) communication, and aim to improve traffic safety and travel comfort of drivers and passengers. Some of these applications include Internet access, content delivery, file downloads, etc.

Thus, several potential applications of inter-vehicle communications require data routing algorithms. So, the design of efficient routing protocols in VANETs is an inherent characteristic of vehicular communications due to the high dynamic network topologies and the high vehicle densities. Traditional ad hoc routing protocols have difficulties in dealing with the high mobility characteristic of VANETs as demonstrated in many studies (Fubler et al., July 2002; Seet et al., 2004) which compare the performance of MANETs topology-based routing protocols (such as AODV (Perkins and Royer, 1999) and DSR (Johnson and Maltz, 1996)) against VANETs position-based (also called geographic) routing protocols in urban as well as in highway traffic scenarios. In contrast to the topology-based routing where the traditional TCP/IP structure is employed to provide an end-to-end communication between nodes, Position-Based Routing (PBR) is based on localization algorithms where each node forwards the packet only based on its location, the location of its neighbouring nodes and that of the destination node. A node forwards the packet to the closest neighbour to the destination. This strategy is called *greedy forwarding* or *geographic forwarding*. Nevertheless, this strategy can fail when there is no available neighbour that is closer to the destination than the current forwarder node. In this case, we say that the node has encountered a local optimal and a recovery strategy must be applied.

Fubler et al. (July 2002; September 2002) have shown that PBR performs well in vehicular movement scenarios, especially for highway environments. However, it has difficulties to deal with two-dimensional scenarios as it is the case for urban environments. This is due to the uneven distribution of vehicular nodes (Song et al., 2015), the mobility constraint and the signal propagation difficulties due to radio obstacles. In fact, urban environments significantly limit the applicability of the greedy position-based routing and the corresponding recovery strategies (Lochert et al., 2003). One of the most well known position-based protocol example is GPSR (Karp and Kung, 2000) that works well in a free open space (no radio obstacles). However, in urban scenarios (Lochert et al., 2003; Seet et al., 2004), surrounded frequently by radio obstacles, its performances deteriorate dramatically.

From our study of position-based routing protocols for VANETs, we have identified several issues that have motivated our proposal:

- (i) We notice that the majority performance problems of position-based routing protocols for VANETs come mainly from connectivity problems. The temporary disconnections in VANETs are unavoidable. It is a practical interest to take into account the real-time vehicular traffic density information, which represents a key factor that influences on the performance of routing protocols in VANETs. Indeed, providing such information to road users would make life more

pleasant on our roads and could indirectly contribute to road safety by influencing driver behaviour. However, the conventional road traffic management systems (Here, Mapmechanics, etc) are based on centralized structure where cameras and sensors installed on the roadsides constantly collect information on the density and the traffic conditions, and transmit this data to a mainframe in order to process and to make the appropriate decisions. Such systems require a large deployment cost, and are also distinguished by a long reaction time for processing and transferring the information in a context where the delay is of a major importance. To overcome the disadvantages of such approaches, some approaches were proposed to decentralize traffic management systems. One of these approaches is *SOTIS* (Self-Organizing Traffic Information System) (Wischhof et al., 2003), where each node calculates periodically its local traffic conditions and propagates them to all its neighbouring nodes. However, this massive propagation may cause saturation of the network bandwidth. Nadeem et al. (2004) have proposed *TrafficView* that allows a given vehicle to have information on vehicles travelling in the opposite direction. From the periodic information exchanges between the two oncoming vehicles, each vehicle includes a mass of data about the position and the moving speed of the other vehicles during an aggregation step. Then, the next step is to return the result of the aggregation so that the driver can get an idea of the opposite traffic. Such a mechanism can estimate real-time traffic conditions in a road segment of a few hundred meters in the opposite direction. It is suitable for driving in a highway environment to facilitate overtaking. However, this mechanism is less useful in urban environments where we need to know the traffic at a road segment before entering in order to give the possibility to the driver to change its direction and thereby, to avoid a possible traffic jam. Jerbi et al. (2009) have proposed *IFTIS* (Infrastructure-Free Traffic Information System). It consists of circulating a same aggregation packet between groups of vehicles through a road segment. This mechanism allows collecting all the traffic density data available on the next segment. However, it provides only an estimation of the traffic on the segments candidates of the forwarding process, and does not provide an enlarged view of the traffic.

- (ii) Another problem that can be identified is the use of a simple greedy forwarding approach for sending data packets along roads. In other words, when choosing a relay vehicle (the neighbour nearest to the destination), most existing position-based protocols do not take into account the direction movement and the position of the vehicles. They consider only the information of the geographical position of the neighbours (the nearest to the destination). This inaccuracy in the positions may adversely affect the performance of the routing protocols, i.e. the choice of the relay vehicle may not be optimal since the selected neighbour is not necessarily the closest to the destination or it is not belonging to the optimal path.
- (iii) The last problem that we consider is the case where the destination has moved away from its knowing position. When a source node wants to transmit data packets to a destination, it must first obtain the geographical coordinates of the latter, by using the digital map of the city in the case where the destination is a static infrastructure or by using a location system² (such as GLS (Li et al., 2000), RLS (Ding et al., 2007), etc.) in the case where the destination is a vehicle. When a source node wants to transmit data packets to a mobile destination, it puts the geographical coordinates (obtained via a location system) of the destination and its position in the packet header. This information will never be updated due to the network overhead that could be engendered. Similarly, if the destination must respond to the source node, the latter could move from its initial position due to its mobility.

² The vast majority of position-based protocols does not use any location service but obtained this information based on the simulator's global view.

Considering all the above issues and taking advantage of the fact that serious transmission decisions are taken at intersections and leads to better performance, we propose in this paper a new position-based routing scheme called *Proactive-optimal-path Selection with Coordinator Agent Assisted Routing* (PSCAR) which uses static nodes as Coordinator Agents and placed at each intersection to assist in making routing decisions. The data packets are forwarded intersection by intersection with the assistance of the Coordinator Agents to quickly reach the destination node. The scheme uses a restricted greedy forwarding form between each two successive intersections, and switches to a carry and forward (Davis et al., 2001) recovery strategy when a local optimal occurs. Since the Coordinator Agents are static nodes, each one knows all the paths to any other Coordinator Agent. Thus, instead of searching an optimal path to the destination node, PSCAR will determine an optimal path to the Coordinator Agent nearest to the destination node so as to better anticipate any change of the destination's position. These paths are updated periodically depending on the changes of the vehicular traffic density.

We also introduce a new distributed density estimation approach based on a fundamental diagram of traffic that allows estimating continuously the vehicular traffic density on road segments.

The remainder of the paper is organized as follows: Section 2 reviews some previous works related to the position-based routing in VANETs. The detailed description of PSCAR is given in Section 3. In Section 4, we present performance evaluation results of the proposed protocol and we conclude the work in Section 5.

2. Related works

Although VANETs is a new technology, diverse position-based routing protocols have been proposed.

GPSR (Karp and Kung, 2000) - *Greedy Perimeter Stateless Routing* is one of the most cited works of the position-based routing. It consists of combining a standard greedy forwarding scheme, which is used whenever possible, with a recovery method called perimeter forwarding used in the case where a local optimal occurs. This perimeter mode uses the long-known right-hand rule for traversing a graph. This rule requires that all the edges are not crossing. Since GPSR works on a free open space scenario, the authors have proposed an approach to obtain a planar graph without crossing the network. However, this approach generates a network overhead. Further, despite the fact that urban environments form natural planar graphs, GPSR shows critical performance degradation when it is applied in such environments (surrounded frequently by obstacles) as demonstrated by Lochert et al. (2003).

GSR (Lochert et al., 2003) - *Geographic Source Routing* combines greedy routing and topology knowledge of the streets to ensure a promising route in the presence of radio obstacles. In GSR, when a source node wants to send a data packet to a destination, it computes a sequence of intersections that the packet traverses in order to reach the destination. This sequence is putted by the source node in the packet header. Then, the packet travels greedily between each two successive intersections. However, despite the fact that GSR outperforms GPSR in terms of packet delivery ratio and average delay, it disregards the case where the path to the destination is not sufficiently dense to route data packets.

A-STAR (Seet et al., 2004) - *Anchor-based Street and Traffic Aware Routing* uses city bus roads information 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 the traffic density is low. A-STAR also employs a recovery strategy when the packets are routed to a local optimal by computing a new anchor path from the local optimal to the destination. However, the traffic density information is deduced statically based on the number of bus road lines which is not an accurate metric for assessing connectivity.

GPCR (Lochert et al., 2005) - *Greedy Perimeter Coordinator Routing* consists of two parts: a restricted greedy forwarding procedure and a repair strategy. The main idea of GPCR is to take advantage of the fact that streets and intersections form a natural planar graph to use the right hand rule when a local optimal occurs. Nevertheless, GPCR depends on coordinator nodes (nodes located at intersections) where the mechanisms proposed for their selection fail on banking and sparse roads. To avoid radios obstacles when selecting greedily the next hop, a coordinator node is preferred even if it is not the closest to the destination. Once a packet reaches a coordinator node, this latter transmits the packet with the same restricted greedy strategy to reach the destination. However, the next street to be taken is determined without considering if there is a sufficient number of nodes on the street.

SADV (Ding et al., 2007) - *Static-node assisted Adaptive data Dissemination protocol for Vehicular networks* is designed to improve the performance under a low or a medium vehicular traffic density. The protocol uses some static nodes at intersections to help transferring data. It introduces three modules: Static Node Assisted Routing (SNAR), Link Delay Update (LDU), and Multi-Path Data Dissemination (MPDD). The SNAR module uses static nodes at intersections to store and to forward the data through the optimal paths. When a packet reaches an intersection, it will be stored in the static node until the best delivery path be available to further deliver the packet. In LDU, the adjacent static nodes measure the link delay in a real time. In addition, MPDD is used to further decrease the packet delivery delay by trying to hit a faster delivery path. However, this mechanism increases the overhead in the network and the delivery delay remains high too.

Another proposed protocol is CAR - *Connectivity-Aware Routing* (Naumov and Gross, 2007), that is based on Preferred Group Broadcast (Naumov et al., 2006) and Advanced Greedy Forwarding (Naumov et al., 2006) mechanisms to provide a scalable low overhead routing in the urban and the highway environments. CAR is able to locate destinations without using an idealized location service. It consists of four main parts: (1) destination location and path discovery; (2) data packet forwarding along the found path; (3) path maintenance with the help of guards; and (4) error recovery. Simulation results show that CAR has a good performance in terms of data delivery rate. However, the first phase of the protocol generates a high network overhead and a high delivery delay.

VADD (Zhao and Cao, 2008) - *Vehicle-Assisted Data Delivery* is based on the idea of the carry-and-forward strategy and on the use of the predictable vehicle mobility. Based on the existing traffic model, a vehicle can find the next road to forward a packet and can select the next forwarding path with the smallest delivery delay. However, this approach considers only the direction of vehicle movement and does not consider the future changes in the network topology.

GyTAR (Jerbi et al., 2009) - *Greedy Traffic Aware Routing* is an intersection-based routing protocol that takes the vehicle density into account in the route selection process. The next hop is chosen by calculating vehicles' travel direction, speed, and by considering the number of vehicles in the intersections. When a local optimal is reached, GyTAR uses the carry and forward strategy where the forwarder node carries the packet and does not transmit it until it reaches an intersection or another node that is closer to the next intersection. However, since the road segments are selected dynamically (step by step), there are some situations where the packet may end frequently on sparse segments which delayed its delivery.

Saleet et al. (2011) propose IGRP - *Intersection-based Geographical Routing Protocol* is based on an effective selection of road intersections, where a packet must pass to reach its destination. The selection of road intersections is made in a way that guarantees with a high probability the network connectivity among the road intersections while satisfying the quality-of-service constraints in terms of tolerable delay, bandwidth usage, and error rate. IGRP achieves significantly good performance. However, simulations are performed under a discrete event simulator on Matlab. This causes some difficulties to perform direct comparisons with other standard simulator results.

Sanguesa et al. (2015) propose RTAD - *A Real-Time Adaptive Dissemination system* that makes each vehicle to automatically adopt the most suitable dissemination scheme in order to fit the warning message delivery policy to each specific situation. It uses as input parameters the vehicular density and the topological characteristics of the environment where the vehicles are located, in order to decide which dissemination scheme must be used. Each vehicle would adopt the most suitable dissemination scheme at the aim of improving the dissemination process. The simulation results have shown that RTAD is able to support more efficient warning message dissemination in all situations ranging from low densities with complex maps, to high densities in simple scenarios.

FDTIS (Gibaud and Thomin, 2015) - *Fully Distributed Traffic Information Systems* is based on vehicle-to-vehicle wireless data transmission that enables traffic self-organization. Alert messages transmitted by vehicles in poor traffic conditions allow receivers to avoid congested roads and reduce travel time. In the specific context of congestion avoidance, the authors present a method that improves the efficiency of traffic alert messages by directing them to the geographic regions where they are most useful. This method uses a past trajectory data from the vehicles involved in a traffic jam which decreases the number of messages. Simulation results have shown that, in the case of intensive traffic, this method prevents saturation of the wireless medium.

OSTD (Mirjazaee and Moghim, 2015) - *an Opportunistic routing based on Symmetrical Traffic Distribution* is proposed for urban scenarios. The proposed algorithm severely considers the type of vehicular distribution in the calculation of an utility function. This utility function is used to evaluate the routes in the network. Vehicle's driving path predictability is also used in the algorithm to forward the packet to a more suitable next hop. Simulation results have shown that OSTD achieves a higher delivery ratio and a lower end-to-end delay compared to the other well-known protocols.

3. PSCAR description

In this section, we describe our proposed PSCAR protocol. Then, we give some assumptions considered in the design and we illustrate the different processes of the protocol.

3.1. General assumptions

As in most position-based routing protocols for VANETs (Ding et al., 2007; Jerbi et al., 2009; Kim and Lee, 2011; Lochert et al., 2005; Mershad et al., 2012; Seet et al., 2004; Wang et al., 2013; Zhao and Cao, 2008) ...etc, we assume that each vehicle can know its geographic position since vehicles nowadays are equipped with a global positioning system (GPS) receiver, which is already popular in new vehicles and will be common in the future. A GPS is often equipped with digital maps. Such kinds of maps have already been commercialized with detailed locations of streets and intersections of the city where the vehicle moves.

Each vehicle periodically broadcasts to its neighbours a Hello-beacon packet reporting its position coordinates and the segment of road where it is located (this beacon packet may also contain other information related to the speed and the direction of the vehicle, etc.). Whenever a node receives such beacon message from a neighbour located in the same road segment, it stores the ID address (example: IP address) and the position coordinates of that node in its neighbour table as well as the timestamp at which the Hello message was received. If a new Hello message is received from the same node, the receiver node updates its information in its neighbouring table. However, if a Hello message is not received from a neighbour node after a period of time ($T= 1$ second), this node is deleted from the neighbours' table.

Also, we assume that when a source node wants to send a data packet to a destination, it must know the geographic position of the latter. This can be done by using the digital map if it is a static

infrastructure or by using a location system³ (such as GLS, RLS, etc.) in the case where the final destination is a vehicle.

PSCAR requires the placement of *static nodes* at each intersection, which is not an expensive infrastructure since wireless technology becomes nowadays pervasive and cheap.

In PSCAR, we call Coordinator Agent (CA) every static node deployed at an intersection (for example, embedded in a traffic signal light). It maintains a path table that contains all the paths toward any Coordinator Agents. This means that each Coordinator Agent has all the paths including the optimal paths to other Coordinator Agents. The optimal paths are selected by the proposed *Proactive-optimal-path Selection* process, and they are updated periodically depending on the variation of the vehicular traffic density.

Each Coordinator Agent broadcasts periodically a beacon message to announce its presence to its neighbours (vehicles or Coordinator Agents).

3.2. The Proactive-optimal-path Selection process

In this section, we describe the proactive-optimal-path Selection process that consists of three different selections to forward the data packet: (1) from a forwarder node to a Coordinator Agent, (2) from the first Coordinator Agent to the last Coordinator Agent, and (3) from the last Coordinator Agent to the destination node.

3.2.1. Optimal-path Selection from a forwarder node to a Coordinator Agent

When a source node S , located at a road segment, wants to send a data packet to a destination node D , first, S gets the geographic position⁴ of D . Once this is done, S determines, from the position of D , the Coordinator Agents which relay the road segment where D is located (the closest Coordinator Agents to D). As shown in figure 1, the closest Coordinator Agents to D are CA(12) and CA(15). In the case where D is located at an intersection, the Coordinator Agent at such intersection is the closest to D .

As well, the source node S determines among the Coordinator Agents CA(2) and CA(5), that CA(5) is the closest to the Coordinator Agent CA(12) than CA(15) in terms of physical distance. So, CA(5) is elected as the next Coordinator Agent to forward the data packet.

We use the physical distance instead of the Euclidean distance (the latter is used by many proposed position-based protocols for VANETs) because the Euclidean distance does not provide the real distances in such networks since the radio obstacles block transmissions. So, the physical distance is used to better take into account the radio obstacles which surround urban environments. By choosing the closest node in terms of physical distance, we ensure finding an available path to the destination, and thereby minimizing the packet transmission delay. Thus, in our model, the packet header will carry only: *the position of the source node, the position of the final destination node* and, *the position of the elected Coordinator Agent* instead of carrying the entire anchor path from the source node S to the destination node D (i.e. the set of all intersections which the packet must traverse to reach its final destination, as it is the case in GSR and A-STAR where the entire anchor path is carrying in the packet header). Thus, this will minimize the packet size and thereby the bandwidth consumption.

Further, the source node forwards directly the data packet to the elected Coordinator Agent if it is within its radio range. Else, the restricted greedy forwarding form is used. For example, in figure 1, S forwards the packet to its neighbour N which is the closest neighbour to the elected Coordinator Agent CA5.

³ How location systems work is outside the scope of the paper.

⁴ In this study, we do not use any location service, but rather obtain the information from the simulator.

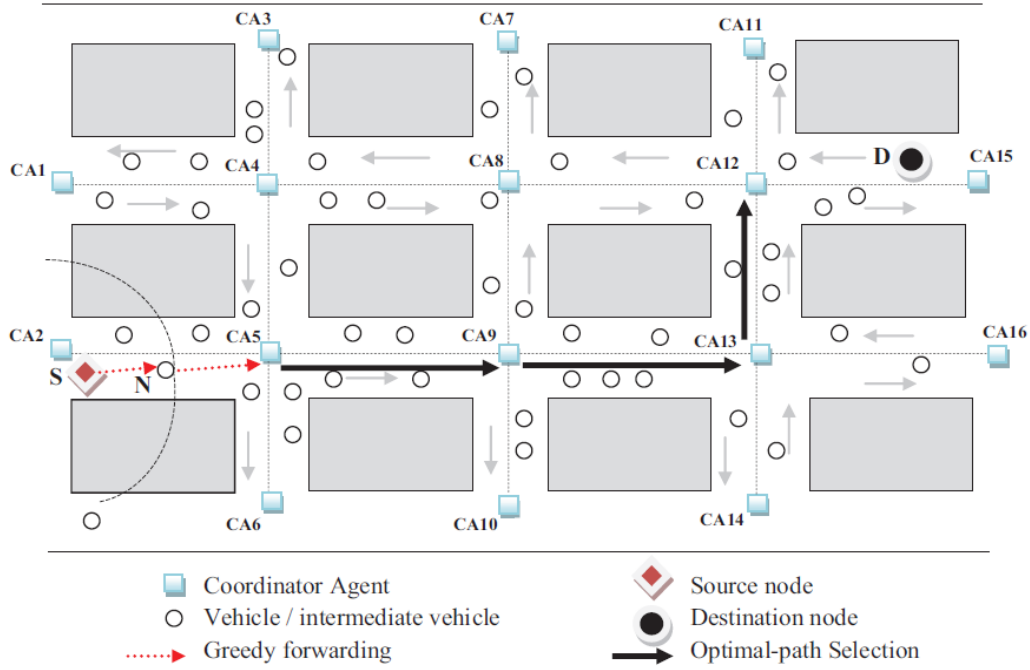


Figure 1: Optimal-path Selection from a forwarder node to a Coordinator Agent.

The basic idea of the greedy forwarding technique is to send the data packet to the neighbour that is geographically the closest to the destination. This process is repeated until the packet reaches its destination. However, this simple greedy forwarding is not often efficient in VANETs, where the vehicles' geographical distribution is strongly restricted by the underlying road structure. Figure 2 shows an example, where the node *C* wants to send a data packet to the destination *D*. By using a simple greedy forwarding, the vehicle *C* will forward the packet to its neighbour *N1*, which is the closest to the destination than *N2* in terms of Euclidean distance. Without taking into account the spatial environment, this decision will lead to a local optimal. However, by restricting this greedy forwarding to the neighbour located on the same segment as the current node *C*, we ensure to avoid the local optimal. Also, by restricting it to the Coordinator Agents, we guarantee to find an existing path to the destination *D*, i.e. the packet is not forwarded to the neighbour that is the closest to the destination node but to the neighbour that is the closest to the next Coordinator Agent and which is located in the same road segment than *C* if the Coordinator node is not directly accessible.

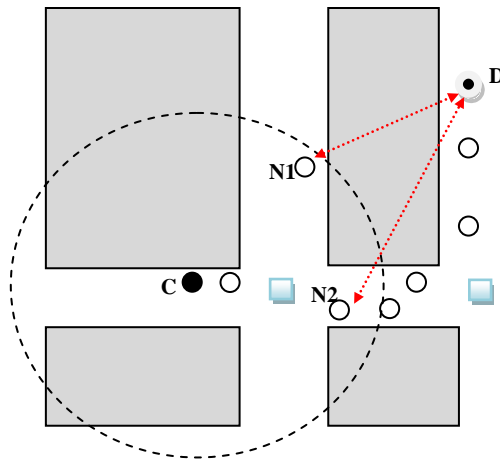


Figure 2: Simple greedy forwarding.

Thus, in figure 1, the source node will search a neighbour, in its neighbours table, that is the closest to CA(5) than itself. So, the neighbour N will be chosen.

Each intermediate node receiving the packet checks, first, if CA(5) is in its neighbourhood. If it is the case, it forwards directly the packet. Otherwise, the restricted greedy forwarding process continues until reaching CA(5). So, forwarding a packet between two successive intersections is done based on the restricted greedy forwarding process where no ‘obstacles’ should block the transmission.

However, a special case can occur: the source and the destination nodes can share the same Coordinator Agents. This means that the source and the destination are located in the same road segment. Here, the restricted greedy forwarding process is used just between the source and the destination nodes, and the packet header will carry only the position of the source and the final destination nodes.

3.2.2. Optimal-path Selection from the first Coordinator Agent to the last Coordinator Agent

Once an elected Coordinator Agent receives the data packet, it has all the paths to other Coordinator Agents. In figure 1, among all available paths from the elected Coordinator Agent CA(5) to the Coordinator Agent CA(12), CA(5) selects the shortest one in which the traffic vehicles, estimated by using our proposal *estimation density approach* (see section 3.4), is sufficiently connected to route the data packets to the destination D . The path $CA(5) \rightarrow CA(9) \rightarrow CA(13) \rightarrow CA(12)$ is one of the shortest paths to CA(12) and which is sufficiently connected to route the data packets. So, the data packet is forwarded to CA(9) using the restricted greedy forwarding strategy if CA(5) cannot reach CA(9) directly. When the packet reaches the Coordinator Agent CA(9), this latter will repeat the same process as CA(5). So, the Optimal-path Selection process from the first Coordinator Agent to the last Coordinator Agent continues until reaching the final Coordinator Agent.

Each Coordinator Agent estimates in continuous and in a distributed manner the density on the segment relaying it to its adjacent Coordinator Agents by using *the proposed estimation density approach* (see section 3.4). This approach will allow the Coordinator Agents to update their respective table containing the connected paths to any other Coordinator Agents. Hence, the proactive approach is used where the path is constructed in advance as in MANETs proactive routing protocols, except the use of the available dense paths’ table to other Coordinator Agents instead of the routing tables.

3.2.3. Optimal-path Selection from the last Coordinator Agent to the destination node

We have two cases to be considered:

- 1) *The destination is a static infrastructure*: when the packet arrives at the last Coordinator Agent, the restricted greedy forwarding is used to reach D . The Coordinator Agent checks, first, if the destination is in its neighbours table. If it is the case, it forwards the data packet to D . Else, it forwards the packet to the closest neighbour to the destination using the restricted greedy forwarding mode until reaching D .
- 2) *The destination is a vehicle*: in the case where the destination is a vehicle, its initial position included in the packet header is never updated in position-based protocols due to the overhead that a location system could generate. So to track the destination, we propose to broadcast the packet only on the segment of road where the destination is located. When the packet arrives to the last Coordinator Agent, this latter checks first if the destination is in its radio range. If it is the

case, it forwards directly the packet; otherwise, it verifies if the destination was a recent neighbour. So, it can know the new direction of the destination (i.e. if it is always on the actual segment or it has changed the segment) based on its velocity vector. Then, it broadcasts the packet on the segment where the destination is located. The broadcast mechanism is limited to the segment of road where the destination is located or where it is moved. In figure 1, when the data packet arrives at CA(15), this latter checks if the destination is passed through it. So, it drops the packet; otherwise, it can know the new direction of D and it broadcasts the data packet on the segment where D is located.

3.3. Local optimal and solutions

Even with the Optimal-path Selection process and the proposed traffic density estimation approach, the risk that a node reaches a local optimal can occur in an urban environment. In this case, a recovery strategy is required so that the data packet is rerouted to reach its destination. In the PSCAR's recovery strategy, the Coordinator Agents also play an important role. We describe, in what follows all scenarios where a local optimal may occur with the solutions to deal with each case.

- *At the source node*: when a source node has elected a Coordinator Agent, it may not have any neighbour closer to the elected Coordinator Agent than itself. In this case, we use the carry and forward strategy, where the data packets are carrying by the source node until one of the following cases be effective:
 - it finds a neighbour which is closer to the elected Coordinator Agent,
 - it reaches itself the elected Coordinator Agent,
 - it reaches another Coordinator Agent (it will be the new elected Coordinator Agent) if it is moving in the opposite direction.
- *At an intermediate node*: in this case, the carry and forward strategy is also used, but here the intermediate node will carry the data packet and if it has reached recently a Coordinator Agent, it will give to this Coordinator Agent a chance to select a new path from the Proactive-optimal-path Selection process. Then, the intermediate node will informs the Coordinator Agent that a local optimal has occurred on the segment where it is located, and the Coordinator Agent marks all the paths including this segment as 'out of service' for a while. This out of service can be made for many reasons: sparse segment, accident on the segment, roadwork on the segment, the failure of the Coordinator Agent, etc. The risk that a local optimal occurs on a segment of an optimal path is very uncommon because PSCAR uses the traffic estimation approach that allows estimating whether a segment is sufficiently dense before sending the data packets.

3.4. Path update based on the density estimation approach

In this section, we describe the distributed mechanism that allows to the Coordinator Agents collecting the density on the segments through exchanged control messages.

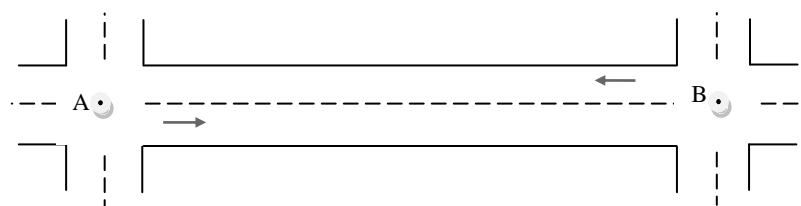


Figure 3: A road segment relaying two intersections.

Based on Coordinator Agents, we propose to use a fundamental diagram of traffic that allows estimating the vehicular traffic density on a road segment relaying two intersections. Hence, we need to verify if a road segment relaying two intersections A and B , as shown in figure 3, has a sufficient density to transmit data packets from A to B and vice versa.

On every segment of the road network and with respect to the behaviour of the vehicles (or the drivers), we define a behavioural law (or a fundamental diagram of traffic). This law defines how drivers respond to the vehicle-density changes on every segment by choosing an appropriate speed. The behavioural law on a segment gives the vehicle-speed in function of the vehicle-density on the segment. It is a non-increasing function, since the vehicle-speed tends to decrease when increasing the vehicle-density (see figure 4). This function is in general approximated basing on data sets. It can also be derived based on the segment characteristics (capacity, maximum density, speed limit, etc.). Vehicles moving on a given segment transmit their velocities to a Coordinator Agent that estimates the average vehicle-speed on the segment. We then use the behavioural law of the segment in order to estimate the vehicle-density in function of the average vehicle-speed on the segment.

We assume here that the behavioural laws on all the segments of the network are given by piecewise-linear curves.

$$v = \min \left\{ v_{max}, \frac{v_{max}}{d_{max} - d_{cr}} (d_{max} - d) \right\} \quad (1)$$

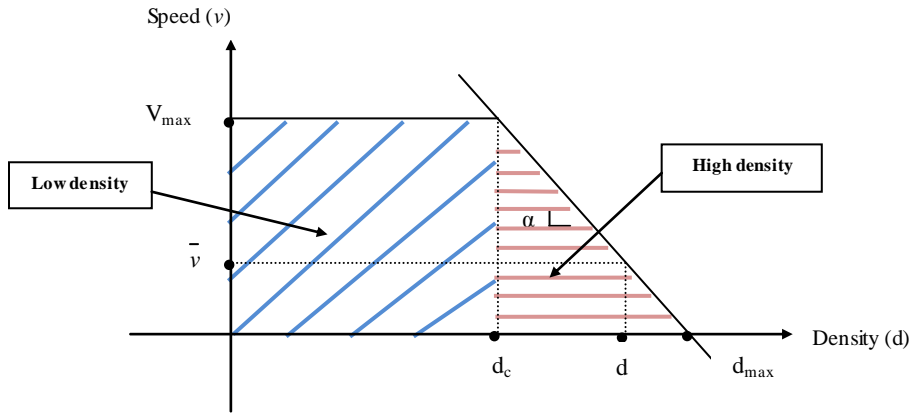


Figure 4: Sample of the fundamental diagram of traffic flow.

Where:

V_{max} : the maximum speed

\bar{v} : the average speed

d_{max} : the maximum density

d_{cr} : the critical density (the congestion limit)

$$d_{max} = \frac{\text{maximum number of vehicles that the road segment can hold}}{\text{length of the road segment}} \quad (2)$$

$$\text{maximum number of vehicles that the road segment can hold} = \frac{\text{the length of the road}}{\text{the average size of a vehicle}} \quad (3)$$

We notice here that a piecewise-linear behavioural law of a given segment is given by three parameters: v_{max} , d_{cr} , and d_{max} .

- Approximate the average speed (\bar{v}) of vehicles on a road segment :

To estimate the traffic on a road segment relating two intersections by using the fundamental diagram of traffic flow, we divide each road segment of the network into a number of cells so that each cell (F) may be covered by at least one vehicle. If we denote by F the length of a cell and by r the radio range of each node, then we should have $F \leq r/2$.

As shown in figure 5, the road segment relating the two intersections A and B is divided into a set of adjacent cells. To estimate the traffic of such road segments, we estimate the density on each cell.

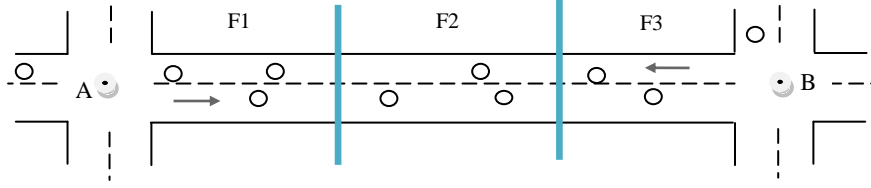


Figure 5: Division of the road segment into cells.

Periodically, a message that we call ‘*Density Estimation Message (DEM)*’ is sent from the Coordinator Agent A to the Coordinator Agent B and vice versa in order to estimate the average speed on each cell of the segment relating A to B.

Each Coordinator Agent generates a ‘DEM’. The latter is sent on the road segments toward the adjacent Coordinator Agents to collect the average speed on each cell in the two directions (i.e. A sends a ‘DEM’ toward B and toward other adjacent Coordinator Agents to estimate the average speed of vehicles).

If a ‘DEM’ is not received from an adjacent Coordinator Agent after a limited time that we have fixed to 8 seconds, then the segment relating it to this Coordinator Agent will be considered *out of service* and the paths table will be updated by putting all the paths including such segment *out of service* for a while.

In figure 5, when the Coordinator Agent A sends a ‘DEM’ on the road segment relating it to B, it forwards the ‘DEM’ to its neighbour vehicle that is located on the cell F1. This neighbour computes the average speed of its neighbours and forwards the ‘DEM’ to a neighbour located on the cell F2 or to a neighbour closer to the cell F2. The node that receives this ‘DEM’ and is located on the cell F2, will process in the same manner until reaching the Coordinator Agent B. When the ‘DEM’ arrives to B, the latter can estimate the traffic density on the segment relating it to A. Then, B can inform its adjacent Coordinator Agents about the traffic density on such segment.

This estimation in both directions can be used to inform drivers about the condition of the traffic in the segment. Therefore, each driver will be warned before it entered in a segment.

For example, if each cell of the segment A to B is dense, the segment is estimated as dense. If there is a path of dense cells on the opposite direction, the road segment relating the two intersections is also considered as dense. From figure 6, we have:

- If the cells 1, 2, 3 or 4, 5, 6 are dense, we say that the segment relating A and B is dense which means that it is connected.
- If the cells 1, 2, 6 or 1, 5, 6 or 1, 5, 3 or 4, 2, 3 or 4, 2, 6 or 4, 5, 3 are dense, we say that the segment relating A and B is connected.

S: source node ; D: destination node ; CA : Coordinator Agent; P : data packet

Run by the source node S

S generates a data packet P destined for D

S runs the Optimal-path Selection :

Determines the closest CAs to D and its closest CAs;

Elects the first CA and the final CA;

If the elected CA is within the radio range of S

S forwards P directly to the elected CA

Else

S forwards P to its closest neighbor using the restricted greedy forwarding

If a local optimal occurs

S starts carrying the packet P **until**:

It finds a closest neighbor to the elected CA **or** it reaches the elected CA or another CA

Run by all vehicles upon receiving a data packet P

If current time – generation time < message lifetime

If the elected CA is within its radio range

Forwards P directly to the elected CA

Else

Forwards P to the closest neighbor to the elected CA, using the restricted greedy forwarding

If a local optimal occurs

Start carrying P until finding a closest neighbor to the elected CA **or** it reaches the elected CA;

If there is a recent CA

Inform it of the local optimal

Else

Drop the data packet

Run by Coordinator Agents upon receiving a data packet P

If current time – generation time < message lifetime

If it is the final CA

If D is within the radio range of the final CA

Forwards P directly to D

Else

If D is a static infrastructure

The restricted greedy forwarding is launched

Else

Broadcast P on the segment road where D is located

Else

If it is the first CA

Selects the Optimal-path to the final CA;

Forwards P to the next CA:

The restricted greedy forwarding is used on the road segment relaying the first CA to the next CA

Else

Selects the Optimal-path to the final CA;

Forwards P to the next CA using the restricted greedy forwarding

Else

Drop the data packet

Figure 7: Pseudo code of PSCAR.

- Calculate the corresponding density d :

The density on a cell is calculated as follows:
$$d = \begin{cases} \in [0, d_{cr}] & , \bar{v} \geq v_{max} \\ d_{max} - \frac{\bar{v}(d_{max} - d_{cr})}{v_{max}} & , \bar{v} < v_{max} \end{cases} \quad (4)$$

Thus, from the fundamental diagram of traffic flow given in figure 4, the vehicle-density on a cell of a road segment is considered as

- Low, when the average vehicle-speed on the cell is higher or equal to the maximum speed v_{max} .
- High, when the average vehicle-speed on the cell is lower than the maximum speed v_{max} .

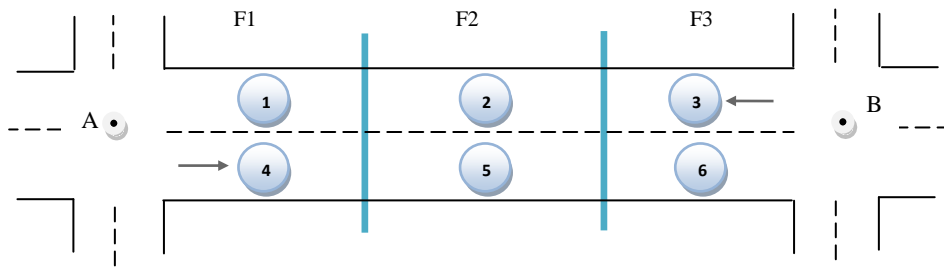


Figure 6: The selection of dense and connected cells.

4. Performance evaluations

Due to the difficulty and the cost of a real experimentation, simulation is often the most used alternative to evaluate proposed approaches for VANETs. So, in this section, we present the simulations performed to evaluate PSCAR and we show its performance in comparison with two well-known protocols: GPCR (Lochert et al., 2005) and A-STAR (Seet et al., 2004).

The simulation of VANETs requires the use of a mobility simulator in addition to a network simulator in order to get results as close as possible to the reality. Thus, we have implemented our proposal by using The Network Simulator 2 (ns-2) (version 2.35) to simulate the network communications, and by using the mobility traces generator SUMO (Simulation of Urban MObility) (version 0.12.3) to generate the vehicles movement traces that must be inputted in ns-2.

4.1. Simulation settings

The street layout considered in the simulations is a grid layout. We set 15 intersections therefore 15 Coordinator Agents. Figure 8 shows the map used in our simulation scenario generated using SUMO. The traffic lights are placed at each intersection. So, the vehicles act according to such traffic lights.

In SUMO, different types of vehicles can be defined. We used this option to differentiate buses from cars which is of interests in A-STAR.

Initially, vehicles start from different intersections and move towards the intersection that is in their directions. When reaching an intersection, a vehicle moves to other outer intersection with different probabilities.

All vehicle movements during the simulation time are saved in a log file. The latter must be considered to generate a mobility trace file used by ns-2 with the help of the *mobility model generator for vehicular networks* (MOVE) (Karnadi et al., 2007) as a connector between mobility and network simulators. First, we started by creating the Map file (net.xml) and the Route file (rou.xml) in which the properties of each vehicle such as vehicle speed, duration of trip, origin and destination of vehicle, vehicle departure time, etc., are specified. Then, the Map file and the different Route files of varied traffic flow were configured to create the corresponding trace files (sumo.tr) which can be visualized using SUMO. Then, the traffic flow of the vehicles is generated using the Traffic Model Generator of MOVE.

The Traffic Model Generator creates the dynamic mobility of vehicular traffic by generating the traffic simulation file used by ns-2. This traffic simulation file includes the location of each vehicle at each instant of the simulation time and its mobility profiles.

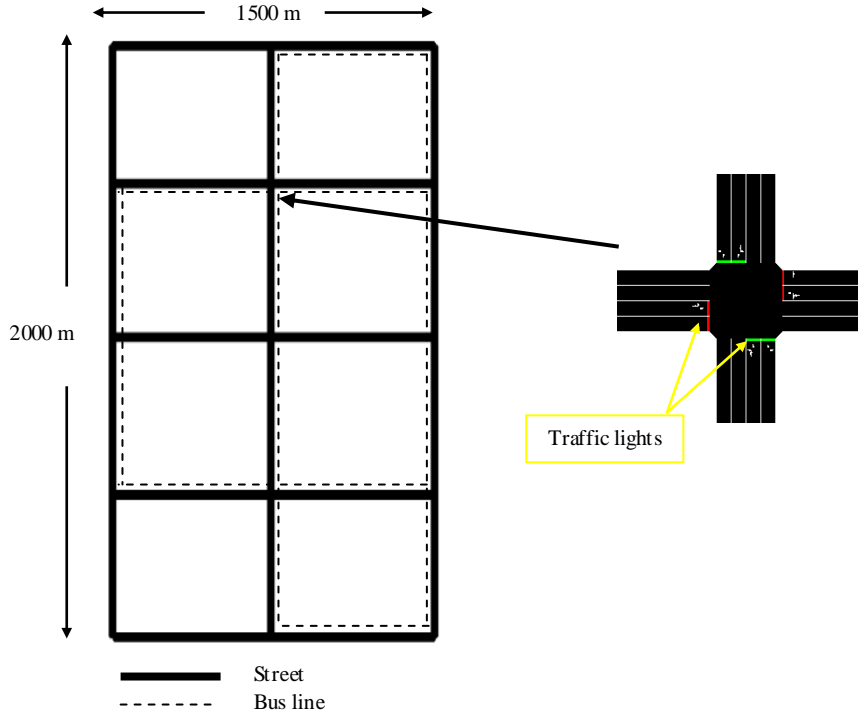


Figure 8: The simulation street map.

The different parameters used in the mobility model and the wireless communications are summarized in Table 1.

<i>Parameter</i>	<i>Value</i>
<i>Simulation area</i>	$2000 \times 1500 \text{ m}^2$
<i>Length of streets</i>	500m, 750m
<i>Number of Coordinator Agents</i>	15
<i>Number of vehicles</i>	40-400
<i>Vehicle velocity</i>	11-50km/h
<i>Traffic model</i>	CBR over 10 random vehicles
<i>Packet type</i>	UDP
<i>Packet size</i>	512 bytes
<i>CBR rate</i>	1packet/second
<i>Hello interval</i>	0.25 second
<i>Transmission range</i>	250m
<i>Propagation model</i>	Two Ray Ground
<i>MAC protocol</i>	IEEE 802.11p
<i>Simulation time</i>	500 seconds

Table 1: Mobility-related and wireless communication-related parameters.

Among all vehicles, 10 of them were randomly chosen to send CBR data packets (10 CBR traffic sources). Each CBR flow uses 512 bytes of UDP packets and sends packets at a rate of 1 packet per second. We used IEEE 802.11p MAC protocol, as it is the most standard choice for VANET simulations.

Each simulation takes 500 seconds. The sources start generating data packets within the first 40 seconds of simulation to allow stabilizing the vehicle density in the entire streets, and stop generating data packets 60 seconds before the end of the simulation to avoid dropping the data packets.

In order to eliminate statistical errors, the results of twenty (20) independent simulation runs were averaged for each scenario. In each simulation run, different sending-receiving pair is used.

4.2. Simulation results and analysis

The performance metrics considered in our evaluations are: *the packet delivery ratio*, *the end-to-end delay*, and *the network overhead*. The *packet delivery ratio* represents the fraction of data packets successfully delivered to their destination. The *end-to-end delay* is the average time that a packet takes to traverse the network from the source to the destination. The network overhead is the total number of control packets (in bytes) transmitted during the simulation including beacon packets.

We compare our protocol with A-STAR and GPCR protocols. A-STAR is the first protocol that takes into account the traffic density. It used information on city bus routes to identify an anchor path with high connectivity for packet delivery. GPCR considers that intersections are the only places where the routing decisions are taken. In order to avoid radio obstacles when selecting greedily the next hop in GPCR, a coordinator node (vehicle at intersection) is preferred that a non-coordinator node even if the coordinator node is not closer to the destination.

The Packet Delivery Ratio (PDR)

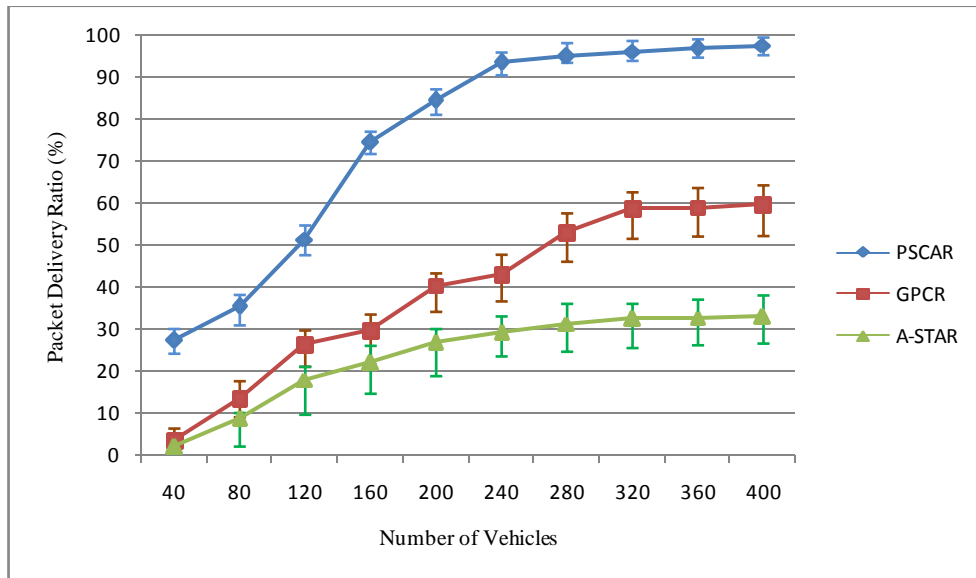


Figure 9: Packet Delivery Ratio over Number of Vehicles.

From figure 9, we show that for all vehicle density scenarios, PSCAR outperforms GPCR and A-STAR. The PDR of PSCAR is upper than 28% for the low vehicle densities and increases as the vehicles density increases to achieve 98% for a high vehicle density. A-STAR presents the lowest PDR for all the vehicle densities compared to PSCAR and GPCR. In fact, A-STAR prioritizes the streets with more bus lines in the routes' selection process. So, most of the data traffic will be oriented to such streets which increases the traffic congestions. GPCR shows a low PDR than PSCAR. This is due to the fact that sending data packets on road segments is done without taking

into account if there are enough vehicles on the road segments to route the data packets to the next coordinator node. In PSCAR, the selection of the road segments to forward the packet is ensured on the basis of its proximity to the destination node and its traffic density that varies in time. This means that the path to send data is not always the same and changes when the vehicular traffic changes, which explains its high delivery ratio.

The End-to-End Delay

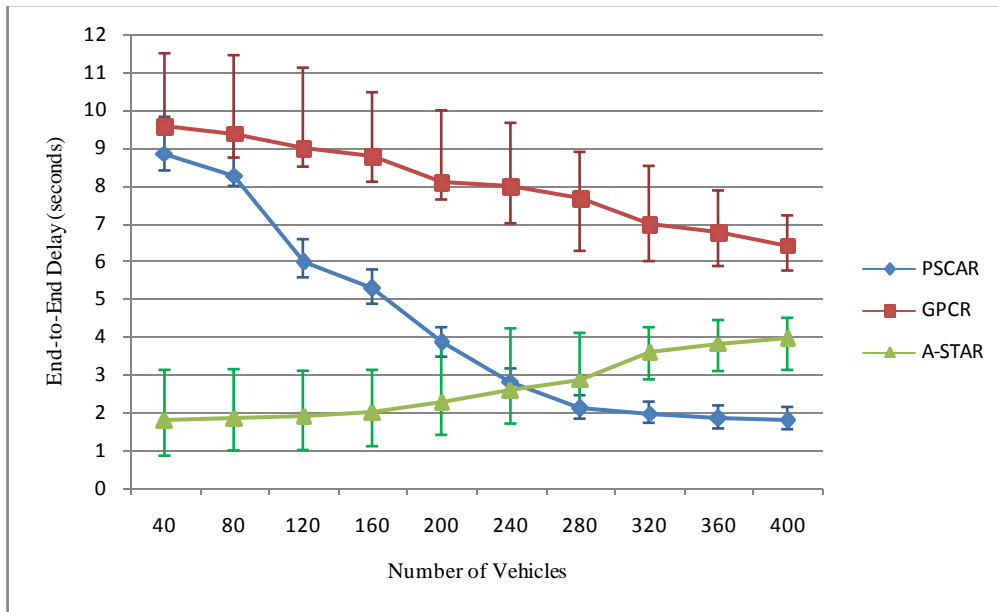


Figure 10: End-to-End Delay over Number of Vehicles.

Similarly, the end-to-end delay (figure 10) seems to be the lowest for PSCAR. This is due to the number of vehicles in the network which improve the connectivity in roads, and also to the use of real connected paths between source and destination pairs. A-STAR and GPCR often fail due to the local optimal recovery strategy. When a local optimal occurs, A-STAR computes another route as a recovery route without taking into account the real traffic density. Since vehicles do not carry packets in A-STAR, a packet is dropped after a limited number of recoveries which explains its low end-to-end delay compared to GPCR and PSCAR. In GPCR recovery mode, the right hand rule is used to recover the data packets from a local optimal. However, this rule is known to be time consuming. In PSCAR, the risk that a local optimal occurs when the network is dense is very low. In fact, before forwarding the packet on a road segment, the Coordinator Agent is aware of the real traffic density. When a local optimal occurs, PSCAR uses the carry and forward strategy and in the same time it will give a chance to the recent Coordinator Agent to choose another path. This explains its high end-to-end delay at the beginning (low densities).

The Network Overhead

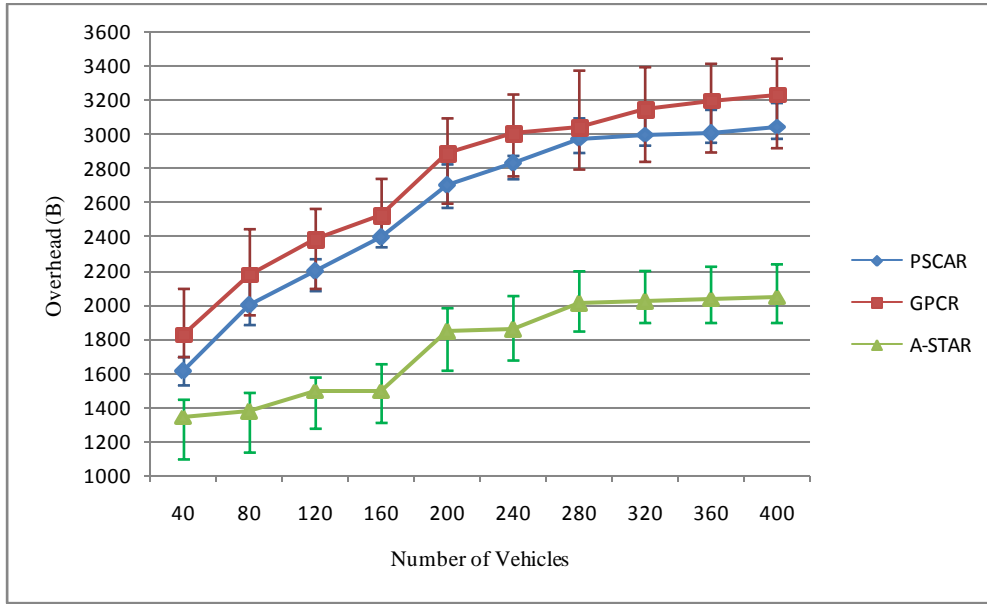


Figure 11: Overhead over Number of Vehicles.

The common network overhead of the three protocols is the number of beaconing message generated during the construction of the neighbourhood tables, which grows proportionally with the vehicular traffic density. In PSCAR, in addition to the beaconing messages, the Coordinator Agents send periodically a message (DEM) to estimate the vehicle traffic density on the road segments connecting them to others adjacent intersections. This mechanism induces some network overhead, but allows harvesting the density traffic on the road segments and helps to find a better routing path, and thus, increasing the packet delivery ratio. The highest overhead observed in figure 11 is that of GPCR. This is due to its mechanism that allows a node to know if it is located at an intersection or not in order to play the role of a coordinator node and to take the decision on which road segment the data should be forwarded. A-STAR presents the lowest overhead in all vehicle density scenarios. However, when the network becomes dense, the overhead of the network increases. In fact, when the number of vehicles increases, the number of hello-beacon messages increases too. In PSCAR, we get a higher delivery ratio and a lower end-to-end delay in contrast to the slight overhead that can be acceptable.

4.3. The impact of the recovery strategy and the distance

In this section, we show the impact of the local recovery strategy and the distance between the source and the destination on the performance of PSCAR.

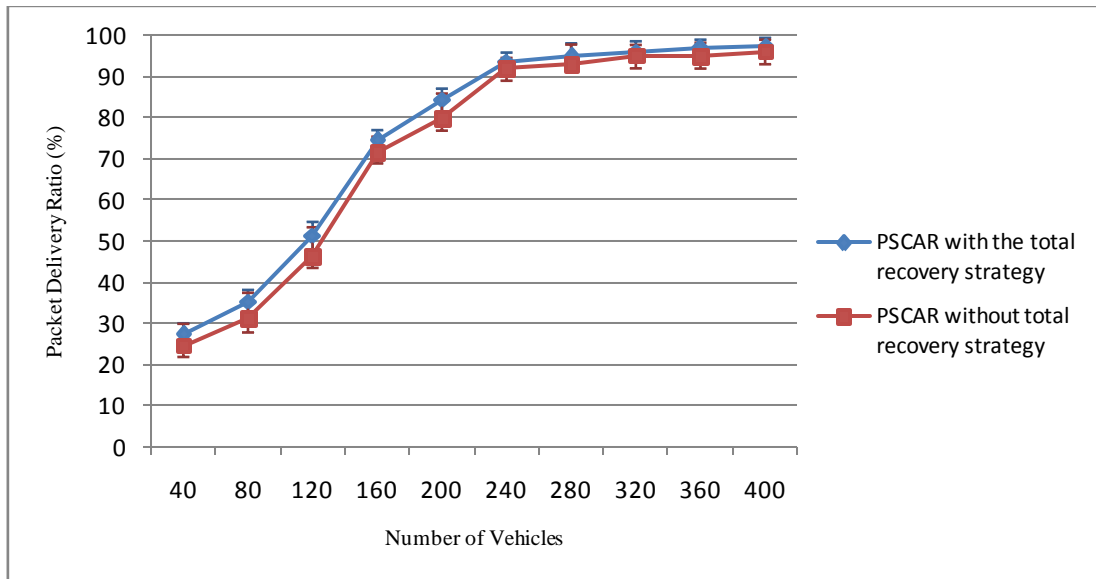


Figure 12: PSCAR and the local recovery strategy.

The total recovery strategy means that when a local optimal occurs, the node carries the packet and at the same time it informs the reached Coordinator Agent that a local optimal has occurred. This will allow the informed Coordinator Agent to choose another path. This total recovery strategy increases the chances of reaching the packet destination and thus it minimizes the delivery delay. Without a total recovery strategy means that when a local optimal occurs, the node carries the data packet without informing the reached Coordinator Agent. So, it carries the packet and does not transmit it until it finds a neighbour closer to the next Coordinator Agent or it reaches itself the next Coordinator Agent. We can observe from the figure 12 that there are no obvious differences. With a total recovery strategy, the packet delivery ratio is improved about 2%. This low rate is explained by the fact that PSCAR takes into account the connectivity information of the road before choosing a path to the destination. Thus, the risk that a local optimal occurs is very low.

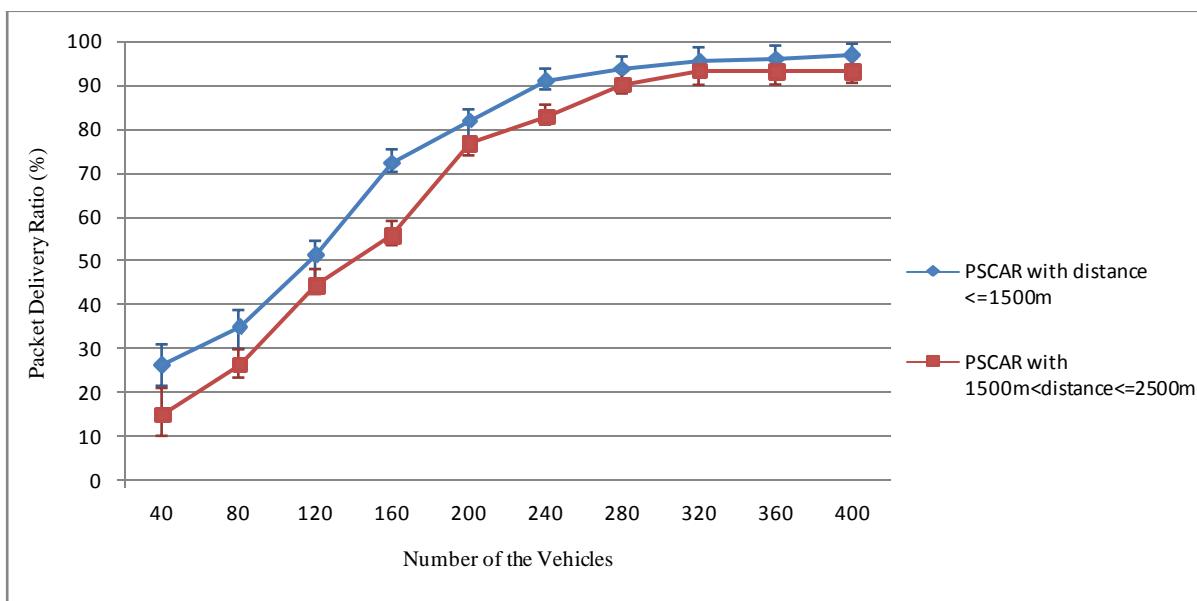


Figure 13: Packet Delivery Ratio vs. the average distance between the source and the destination.

Figure 13 shows the results of packet delivery ratio for PSCAR when the distance between the source and the destination nodes is less than or equal to 1500m, and when this distance is more than 1500m and less than or equal to 2500m. When the distance between the source and the destination increases, we notice a slight decrease in the packet delivery ratio for low density scenarios. When the destination is far from the source, the data packets' lifetime decreases. In fact, in low density scenarios, the packets have more chance to fall in the local optimal. However, with the increase of vehicles density and the distance between the source and the destination, the packet delivery ratio is sufficiently high. Hence, we note that the distance between the source and the destination is not a major factor that can influence on the delivery ratio but rather the density of the path.

5. Conclusion and future works

In this paper, we have proposed a new position-based routing protocol for VANETs called Proactive-optimal-path Selection with Coordinator Agent Assisted Routing (PSCAR). The main idea is the use of Coordinator Agents placed at intersections to assist the routing process. The protocol uses a restricted greedy forwarding and a carry and forward recovery strategies. We also introduced a novel density estimation approach which allows estimating the density traffic on a segment of road connecting two successive intersections. This mechanism can also be used in different application scenarios such as preventing the drivers on the density traffic of the network, for example, at an intersection to avoid entering a congested segment. Despite the additional overhead generated in the estimation of the road traffic, our protocol demonstrates much better performance and outperforms GPCR and A-STAR routing protocols in terms of packet delivery ratio and end-to-end delay for the different densities of vehicles.

Furthermore and as future works, we intend to evaluate the performance of the proposed protocol by considering the large-scale networks. We also plan to make the beaconing phase more efficient and we may adopt the idea of an adapting beaconing period where the beaconing interval changes according to the velocity vector of nearby neighbours. On the other hand, we need to redo the simulation with a realistic street map and we envisage using the TIGER database [TIGER] which provide more realistic road network than a simple grid network.

References

- Gibaud, A., Thomin, P. (2015) 'Message forwarding based on vehicle trajectory history in Fully Distributed Traffic Information Systems, *Computer Communications*, Vol. 60, Issue C, pp. 40-52.
- Bilal Sardar, M., Bernardos, C.J. and Guerrero, C. (2013) 'Position-based routing in vehicular networks: A survey', *Journal of Network and Computer Applications*, Vol. 36, No. 2, pp. 685-697.
- Davis, J., Fagg, A. and Levine, B. (2001), 'Wearable Computers as Packet Transport Mechanisms in Highly-Partitioned Ad-Hoc Networks' in *Proceedings of the 5th International Symposium on Wearable Computers*, Zurich, 8-9 October 2001, pp. 141-148.
- Ding, Y., Wang, C. and Xiao, L. (2007), 'A Static-Node Assisted Adaptive Routing Protocol in Vehicular Networks' in *Proceedings of The 4th ACM International Workshop On Vehicular Ad Hoc Networks (VANET'07)*, Montréal, Québec, Canada, 10 September 2007, pp. 59-68.
- Fußler, H., Mauve, M., Hartenstein, H., Kasemann, M. and Vollmer, D. (2002) 'A Comparison of Routing Strategies for Vehicular Ad Hoc Networks' *Department of Computer Science, University of Mannheim, Tech. Rep. TR-02-003*, July 2002.
- Fußler, H., Mauve, M., Hartenstein, H., Kasemann, M. and Vollmer, D. (2002), 'Location-Based Routing for Vehicular Ad-Hoc Networks' *International Conference on Mobile Computing and Networking (MOBICOM '02)*, Atlanta, Georgia, USA, 23-28 September 2002.
- Hechri, A., Hmida, R. and Mtibaa, A. (2015), 'Robust road lanes and traffic signs recognition for driver assistance system' *International Journal of Computational Science and Engineering*, Vol. 10, No. ½, pp. 202-209.

Here. <<http://www.traffic.com>>.

Johnson, D.B. and Maltz, D.A. (1996) 'Dynamic Source Routing in Ad Hoc Wireless Networks' *Mobile Computing, Imielinski T and Korth H, Editors, Chapter 5, The Kluwer International Series in Engineering and Computer Science*, Vol. 353, pp. 153-181.

Jerbi, M., Senouci, S.M., Rasheed, T. and Ghamri-Doudane Y. (2009) 'Towards Efficient Geographic Routing in Urban Vehicular Networks' *IEEE Transactions on Vehicular Technology*, Vol. 58, No. 9, November 2009, pp. 5048-5059.

Karp, B. and Kung, H.T. (2000) 'Gpsr: Greedy perimeter stateless routing for wireless networks' in *Proceedings of the 6th ACM international conference on Mobile computing and networking (MobiCom '00)*, Boston, Massachusetts, July 2000, pp. 243-254.

Karnadi, F.K., Mo, Z.H. and Lan, K. C. (2007) 'Rapid Generation of Realistic Mobility Models for VANET' *IEEE Wireless Communications and Networking Conference (WCNC)*, Kowloon, 11-15 March 2007, pp 2506 - 2511.

Kim, J.H. and Lee, S. (2011) 'Reliable routing protocol for Vehicular Ad Hoc Networks', *AEU-International Journal of Electronics and Communication*, Vol. 65, No. 3, pp. 268-271, March 2011.

Li, J., Jannotti, J., De Couto, D., Karger, D. and Morris, R. (2000) 'A scalable location service for geographic ad hoc routing' in *Proceedings of the 6th annual international conference on Mobile computing and networking (MobiCom'00)*, pp. 120-130.

Lochert, C., Hartenstein, H., Tian, J., Herrmann, D., Fußler, H. and Mauve, M. (2003) 'A Routing Strategy for Vehicular Ad Hoc Networks in City Environments' in *Proceedings of the IEEE Intelligent Vehicles Symposium*, 9-11 June 2003, pp. 156-161.

Lochert, C., Mauve, M., Fußler, H. and Hartenstein, H. (2005) 'Geographic Routing in City Scenarios' *ACM SIGMOBILE Mobile Computing and Communications Review*, Vol. 9, No. 1, January 2005, pp. 69-72.

Mapmechanics. <<http://www.mapmechanics.com>>.

Mershad, K., Artail, H. and Gerla, M. (2012) 'ROAMER: Roadside Units as message routers in VANETs', *Ad Hoc Networks*, Vol. 10, No. 3, pp. 479-496.

Mirjazaee, N., Moghim, N. (2015) 'An opportunistic routing based on symmetrical traffic distribution in vehicular networks', *Computers and Electrical Engineering*, Vol. 47, pp. 1-12.

Nadeem, T., Dashtinezhad, S., Liao, C. and Iftode, L. (2004) 'TrafficView: Traffic Data Dissemination using Car-to-Car Communication' in *ACM Mobile Computing and Communications Review (MC2R), Special Issue on Mobile Data Management*, Vol. 8, No. 3, July 2004, pp. 6-19.

Naumov, V., Baumann, R. and Gross, T. (2006) 'An Evaluation of Inter-Vehicle Ad Hoc Networks Based on Realistic Vehicular Traces' in *Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing (MobiHoc '06)*, Florence, Italy, 22-25 May 2006, pp. 108-119.

Naumov, V. and Gross, T.R. (2007) 'Connectivity-Aware Routing (CAR) in Vehicular Ad Hoc Networks' in *Proceedings of IEEE International Conference on Computer Communications*, Anchorage, AK, 6-12 May 2007, pp. 1919-1927.

ns-2 -The Network Simulator 2. <<http://www.isi.edu/nsnam/ns>>.

Perkins, C.E. and Royer, E.M. (1999) 'Ad-Hoc On-Demand Distance Vector Routing' in *Proceedings of IEEE Workshop on Mobile Computing Systems and Applications (WMCSA)*, New Orleans, LA, 25-26 February 1999, pp. 90-100.

Pu, L., Xu, X., He, H., Zhou, H., Qiu, Z. Hu, Y. (2015) 'A flexible control study of variable speed limit in connected vehicle systems' *International Journal of Embedded Systems*, Vol.7, No.2, pp.180-188.

Seet, B.C., Liu, G., Lee, B.S., Foh, C.H., Wong, K.J. and Lee, K.K. (2004) 'A-STAR: A Mobile Ad Hoc Routing Strategy for Metropolis Vehicular Communications' *NETWORKING 2004*, Vol. 3042, pp. 989-999.

Saleet, H., Langar, R., Naik, K., Boutaba, R., Nayak, A. and Goel, N. (2011) 'Intersection-based geographical routing protocol for VANETs: A proposal and analysis' *IEEE Transactions on Vehicular Technology*, Vol. 60, No. 9, November 2011, pp. 4560-4574.

Sharef, B.T., Alsaqour, R.A. and Ismail, M. (2014) 'Vehicular communication ad hoc routing protocols: A survey', *Journal of Network and Computer Applications*, Vol. 40, April 2014, pp. 363-396.

Simulation of Urban Mobility - SUMO. *Centre for Applied Informatics (ZAIK), Institute of Transport Research, German Aerospace Centre*. <<http://sumo.sourceforge.net>>.

- Sanguesa, J.A., Fogue, M., Garrido, P., Martinez, F.J., Cano, J.C., Calafate, C.T., Manzoni, P. (2015) 'RTAD: A real-time adaptive dissemination system for VANETs', *Computer Communications*, Vol. 60, pp. 53–70.
- Song, Z., Zhou, S., Luo, J. and Deng, W. (2015) 'The B⁺-tree-based method for nearest neighbour queries in traffic simulation systems' *International Journal of High Performance Computing and Networking*, Vol.8, No.2, pp.110-123.
- TIGER (Topologically Integrated Geographic Encoding and Referencing), <http://www.census.gov/geo/www/tiger>.
- Wischhof, L., Ebner, A., Rohling, H., Lott, M. and Halfmann R. (2003) 'SOTIS – A Self-Organizing Traffic Information System' *IEEE Vehicular Technology Conference (VTC)*, 22-25 April 2003, Vol. 4, pp. 2442-2446.
- Wang, X., Li, C., Zhu, L. and Zhao C. (2013) 'An Effective Routing Protocol for Intermittently Connected Vehicular Ad Hoc Networks' in *Proceedings of the Wireless Communications and Networking Conference (WCNC) IEEE*, Shanghai, 7-10 April 2013, pp. 1750-1755.
- Zhao, J. and Cao, G. (2008) 'VADD: Vehicle-assisted data delivery in vehicular ad hoc networks', *IEEE Transactions on Vehicular Technology*, Vol. 57, No. 3, May 2008, pp. 1910-1922.