

Routing in Vehicular Ad Hoc Networks: Towards Road-Connectivity Based Routing

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1. Introduction

The proliferation of wireless technologies has inspired researchers from both academia and automotive industry to integrate advanced capabilities to the vehicles and provide new services and mobile applications. In particular, vehicular networks have emerged as a novel class of Mobile Ad Hoc Networks (MANETs) formed between moving vehicles equipped with wireless devices. Based on multi-hop communications, these self-organizing networks enable data exchanges among nearby vehicles and between vehicles and the road side infrastructure.

Driven by the transportation safety and efficiency issues, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications are attracting considerable attention in providing Intelligent Transportation Systems (ITS). In this context, a variety of services are offered to road users for improving their security and comfort. These emerging applications include among others safety applications for traffic monitoring and collision prevention, road information services, and infotainment and so on.

However, unlike other ad hoc networks, Vehicular ad hoc Networks (VANETs) have their unique characteristics which give rise to many challenging issues. One of the most salient features is the high mobility of vehicles resulting in dynamic topology changes. Accordingly, data routing remains a key networking issue that needs to be addressed in order to support the emerging applications. Over the last decades, many efforts have been concerted to design efficient routing protocols after recognizing the inefficiency of traditional MANET protocols to meet the requirements of vehicular environments.

This chapter presents an analysis of the routing problem in vehicular ad hoc networks. First, it discusses the main characteristics and challenges of VANETs that distinguish them from the traditional MANETs. Then, it reviews the most relevant routing strategies proposed in the research community highlighting their advantages and disadvantages.

Based on these considerations, we introduce a new class of geographic routing protocols called RCBR, Road Connectivity-based Routing for vehicular networks. The proposed approach exploits information about road connectivity and vehicles distribution to find stable routes and reduce the probability of links breakage. Simulations results are used to show how traffic awareness combined with a spatial knowledge of the environment can optimize the routing decisions in high dynamic networks.

2. Routing protocols in vehicular networks

This section presents a brief overview of routing protocols proposed or adapted for vehicular ad hoc networks. According to the type of information used to make the routing decisions, these protocols can be classified into 5 categories as shown in figure 2.1. In the following subsections, we describe the principal protocols in each group and analyses their adaptability for VANETs scenarios.

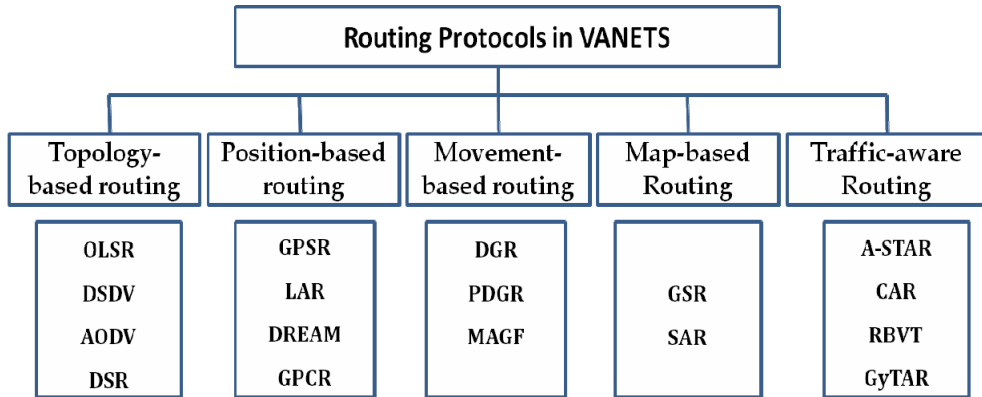


Fig. 1. Taxonomy of existing routing protocols in vehicular ad hoc networks

2.1 Topology-based routing

The *topology-based* protocols use the information about the network topology and the state of communication links between nodes to perform the routing decisions. They can be further categorized into proactive and reactive approaches.

The proactive protocols, such as Optimized Link State Routing (OLSR) (Clausen et al., 2001) and Destination-Sequenced Distance-Vector Routing (DSDV) (Perkins & Bhagwat, 1994) compute and maintain routing information about all available paths in the networks even if no data traffic is exchanged. For instance, in DSDV, every node maintains a vector of distances to every known destination. Therefore, frequent broadcast messages are issued by all nodes to learn periodically about their 1-hop neighbors or to advertize topology changes (e.g. link breakages). Similarly, OLSR floods the network by the topology control messages in order to disseminate the link states information throughout the entire network showing which nodes are connected to which other nodes.

This additional traffic used in proactive approaches for the maintenance of unused paths has several drawbacks. First, it consumes the networks resources and wastes a part of the bandwidth for control messages that increase with rapid changes. Moreover, the use of flooding increases the network congestion and leads to the loss of messages because of collision. They face a trade-off between the freshness of the routing information and the control overhead. Clearly, proactive solutions do not scale well in very large networks with a high number of nodes joining and leaving the network over a short time, which is the case for VANETs.

On the contrary, reactive protocols such as AODV (Perkins & Royer, 1999) and DSR (Johnson & Maltz, 1996) determine a route to a given destination only on-demand. They

reduce the overhead by restricting the route maintenance only between nodes that need to communicate. In other words, route discovery is only initiated when a sending node has to set up a valid path towards a given destination. Obviously, this extends the delay before that the packets could be actually sent through the network. In addition, most of reactive protocols use the flooding technique to establish the communication between the source and destination and consequently, consume a lot of the available bandwidth.

Because of the high mobility of vehicles, the topology-based algorithms fail to handle frequent broken routes usually constructed as a succession of vehicles between the source and the destination. Moreover, the route instability and frequent topology changes increase the overhead for path repairs or change notifications and thus, degrade the routing performances.

Generally, in topology-based approaches, routing paths are built as successions of mobile nodes, and hence the chance of losing the connectivity is higher. Therefore, they are not suitable for vehicular scenarios and no further investigation will be done on their applications in these extremely dynamic environments.

2.2 Position-based routing

Position-based protocols perform the routing decisions based on the geographic information of the nodes. This class offers an alternative approach known to be more robust to face the mobility issues (Giordano & Stojmenovic, 2003). Indeed, no global knowledge of the network topology is required; a purely local decision is made by each node to make a better progress towards the destination. Therefore, they require all nodes to be aware of their physical positions as well as their neighbours' positions. They also assume that the sending node knows the position of the destination. Typically, a location management service is responsible for querying this information (Li et al., 2000).

2.2.1 Greedy perimeter stateless routing

As a representative example of the position-based algorithms, Greedy Perimeter Stateless Routing (GPSR) seems to be the most popular candidate for dynamic networks (Karp & Kung, 2000). Typically, there are several requirements on the availability of position information: GPSR requires that each node is able to obtain its current location e.g., through a GPS receiver as it is becoming standard equipment in vehicles. Furthermore, it assumes that each node learns about the existence of its direct neighbors and their current positions through the exchange of periodic HELLO messages. To make the routing decisions, a source node needs to know the position of the destination. The source node forwards the packets to its neighbor which is geographically closest to the destination. This procedure, known as Greedy Forwarding, is recursively applied by intermediate nodes until the final destination is reached. However, packets can reach node that has no neighbor which is closer to the destination than itself. This problem known as local maximum is likely to happen in case of sparse networks.

In such a case, GPSR switches to a recovery strategy called Perimeter Mode using the right hand rule algorithm of planer graph traversal to route the packets out of the local maximum region. Being expensive this recovery procedure is abandoned as soon as possible to go back to the greedy strategy since it can decrease the performance when used often.

Nevertheless, using only the position information may lead packets to be forwarded a wrong direction and loses consequently good candidates that ensure its delivery. As

shown in figure 2, following a position-based approach the packets take the direction of the node A instead of the destination D facing so a local maximum problem.

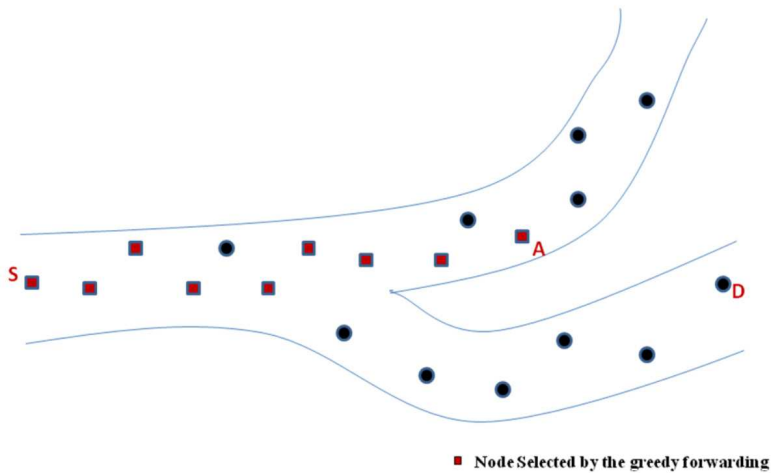


Fig. 2. Failure of Greedy Forwarding by selecting wrong direction

2.3 Movement-based routing

Numerous protocols enhance the basic position-based scheme to optimize the routing decisions. Indeed, due to the local maximum problem packet drops still occur using only position information. To address this shortcoming, some approaches like Directional Greedy Forwarding (DGR) (Gong et al., 2007) and Movement Aware Greedy Forwarding (MAGF) (Brahmi et al., 2009) suggest making use of additional information about vehicles movement such as direction and speed. The basic idea is to compute a weighted score W_i as a function of different factors (position, direction, speed) for assigning priority between neighboring nodes while selecting the next forwarder. This enhancement of the pure position-based scheme reduces the number of encountered local maximum by avoiding sending packets away from the destination while selecting a wrong direction.

Considering the fact that vehicles follow a predictable mobility pattern, the authors of (Gong et al., 2007) propose Predictive Directional Greedy Routing (PDGR) to forward packet to the most suitable next hop based on both current and predictable future locations. The mobility prediction scheme allows a packet relay to ensure the validity of a selected neighbor.

These enhanced solutions are likely to fit more to highway scenarios than to city-scenario where the topology of road determines the movement and the behaviours of cars.

2.4 Map-based routing

The Map-based routing protocols combine the position information with topological knowledge about the road and the surroundings. The idea is to build a spatial model representing the underlying road topology and select a routing path that overlaps with the streets. For this purpose, the road maps are represented by graphs where vertices are crossroads and edges are road segments. Commonly, the edges of the graph are weighted with static data extracted from the street maps. Examples of these static data could be

distance, travel time or speed limits. Accordingly, the routing path is selected based on the new constructed graph and the data packets are only forwarded respecting the particular mobility pattern restricted by the road topology.

These approaches vary from source routing approaches, where the entire path towards the destination is pre-computed by the data source, to the dynamic routing where decisions are made only at road intersections based on various parameters.

As example of protocols that belong to this class we present in the following sub-sections Geographic Source Routing (GSR) (Lochert et al., 2003) and Spatial Aware Routing (SAR) (Tian et al., 2003).

2.4.1 Geographic source routing

The first protocol to use the knowledge of the underlying map of the streets was Geographic Source Routing (GSR) which is mainly proposed for urban environments. (Lochert et al., 2007). Assuming the availability of such information through a navigation system, a given source computes the shortest path to an intended destination using Dijkstra's algorithm based on the distance metric. The computed path consists of a sequence of junctions IDs known as Anchor Points (AP), along which packets should be forwarded to reach the destination. These anchors, obtained from the streets map, reflect the underlying road topology and usually represent the road intersections where decisions are made. The list of junctions is then inserted into the header of each data packet sent by the source.

The packets are forwarded over the selected path successively from one AP to the next AP using the greedy forwarding scheme. Moreover, it is important to note that the authors make use of a reactive location service to retrieve the current position of a desired destination. Concretely, the source node floods the network to query the location of a specific distant node and thus, leads to bandwidth wastes.

The studies conducted to compare GSR with topology-based protocols show the advantage of this map-based approach in realistic vehicular environments. However, it should be noted that the insertion of the entire path in the packet's header cannot be preferred in case of a long route between the source and the destination since it causes an additional packet overhead. Furthermore, assuming the connectivity of the shortest path is not realistic since it does not consider situations where there is no sufficient number of vehicles on the road between two involved junctions to ensure the road connectivity. That is, if along one road segment the packets face a local maximum situation that prevent them from progressing towards the next AP, they are directly discarded although an alternative longer path may exist.

2.4.2 Spatially aware packet routing

The authors of (Tian et al., 2003) introduce the Spatially-Aware Packet Routing (SAR) protocol to improve the basic GSR with a recovery procedure to avoid a local maximum. As we have already noted, the greedy routing used to forward packets along the shortest path may fail if there are no vehicles ensuring connectivity to the next intersection. In such situations, GSR drops the packets although a valid path may exist. On the contrary, SAR suggests finding an alternative path from the current location where the local maximum occurs and then replaces the original route with the new one. The new path is computed again using Dijkstra algorithm after removing the current road segment where the local maximum is detected. According to the authors, another option would be to store the packet

in a suspension buffer and wait for an incoming neighbor that provides positive progress towards the next intersection. The suspended packets will be dropped if the buffer is full or if they cannot be forwarded during a predefined interval depending on the application requirements. Although these recovery procedures are defined to be used separately, it seems advantageous to combine both mechanisms to decrease the risk of packet drop.

The performances evaluation has shown that SAR is more robust to the mobility than topology-based routing protocols (DSR) since the routing path is computed independently of specific mobile nodes.

Although knowing the road topology represents a big advantage, this approach fails in the case where the algorithm tries to forward packets over streets where no vehicles are moving. Moreover, frequent network partitions can cause path disconnections and prevent packets from progressing towards their destinations. These problems were addressed by extending the road topology knowledge with the vehicular traffic awareness. The following subsection presents some representative examples of such protocols that include information about vehicular traffic and density in addition to basic street-level data extracted from digital maps.

2.5 Traffic-aware routing

The traffic-aware routing protocols suggest the use of available data about vehicular traffic density and flows in addition to spatial information. Thus, only streets where vehicles are moving will be used for packet forwarding. The following sub-section examines examples of such routing solution which are designed using traffic information.

2.5.1 Anchor-based street and traffic aware routing

One of the protocols that exploit the idea of traffic awareness in designing a routing scheme is the Anchor-based Street and Traffic-Aware Routing (A-STAR) (Lee et al., 2004). Generally, in city environments, vehicles are concentrated more in some areas than in others and hence the connectivity is higher in these roads. A-STAR added a new feature to the basic GSR using historical information on bus traffic to identify anchor-based paths with the highest connectivity according to the bus traffic regularity. It builds a weighted graph where edge's weight is assigned based on the number of bus lines that traverse the road segment. The more the bus lines are, the more stable the traffic is and so the less weight attributed to the road is. Then, the anchor route is constructed using the Dijkstra's algorithm applied to the produced graph. The bus traffic information can be extracted from statically rated maps with preconfigured routes or from dynamically rated ones where the street traffic is updated periodically based on road-side units. In A-STAR, the packets are forwarded along the defined route on the same way defined in SAR. Besides, the authors define a recovery procedure similar to the one used by SAR to counter local maximum. It consists of computing an alternative anchor route from the local maximum to the destination. To prevent other packets from traversing the same area, a road segment where a local maximum is detected is marked as out of service (OFF). This information is afterwards disseminated in the network to update the graph so that these routes will not be used for new paths computation.

The study comparing the protocol to other existing protocols like GPSR and GSR show that the traffic information are useful for routing in VANETs. Nevertheless, the authors do not give any indication about the network overhead generated in order to monitor the city traffic condition and distribute such information to every vehicle.

In addition, it seems worthy to observe that historical data, such as bus traffic, cannot always accurately describe the current road traffic conditions since road congestion and events like road constructions cannot be detected. This makes the protocol inappropriate for highly dynamic environments. Based on this observation, new approaches propose to investigate more the use of real traffic information.

2.5.2 Connectivity aware routing

Yang et al. propose Connectivity Aware Routing protocol (Yang et al., 2008) which uses the statistical data collected by different vehicles to estimate the probability of connectivity of each road segment. In their model, the authors consider also the clustering phenomenon resulting from vehicles movement affected by the traffic light. The connectivity information is disseminated in the entire network to provide a global vision about the network connectivity. Based on that, a connectivity graph is defined from a combination between road topology information extracted from digital maps and the gathered connectivity information. For packet routing, CAR uses Dijkstra's algorithm to compute the optimal path along which packets will face the least probability of network disconnection. In other words, the route with the highest probability of connectivity is selected as the routing path.

The simulations studies have shown that the real-time information used in CAR improves the performances of routing in VANETs compared to GPSR and GSR. However, no indication was given about the overhead generated by collecting and exchanging connectivity information about the entire network especially that this information is volatile due to vehicles mobility. Since CAR relies on the statistic traffic data, the authors propose to investigate in their future work how they can further improve the protocol's performances by exploiting real-time traffic information.

2.5.3 Road-based with vehicular traffic

Recently, a group of Road-Based with Vehicular Traffic protocols (Nzouonta et al., 2009) has been proposed for VANETs. These protocols incorporate real-time vehicular traffic to compute road-based paths consisting of successions of road intersections connected among them through vehicular communications. Two variants of RBVT are presented: a reactive protocol, RBVT-R, and a proactive protocol, RBVT-P. In RBVT-R, only source nodes discover the connected road segments on demand by initiating route discovery packets which traverse the network towards the destination. Being a source routing, RBVT-R includes the discovered routes in the packets headers and utilizes a greedy forwarding procedure to transmit packets along road segments forming the selected path. On the other hand, RBVT-P maintains a graph of all connected road segments. To discover the network topology, connectivity packets (CP) are generated periodically by multiple vehicles randomly selected in the network. Each node decides independently whether to generate a new CP based on the estimated current number of vehicles in the networks, the historic hourly traffic information and the time interval since it last received a CP update.

These packets traverse the road map and record the road segments with enough vehicular traffic before returning to the generator segment. Using the collected information, any vehicle belonging to that segment which receives the CP after all intersections marked are visited will construct the connectivity graph and disseminate it in the entire network. Then, the shortest path to the destination is computed only from the road segments that are marked as connected. The evaluation study comparing RBVT to topology-based routing,

position-based routing and map-based routing show an improvement in its performances when used for dynamic vehicular networks. This improvement is due to real-time traffic consideration that makes routing decisions adapted to network conditions. Nevertheless, this procedure generates an additional overhead to maintain the freshness of the topology information. More adapted and suitable schemes for providing the connectivity information should be used to improve the scalability of RBVT protocols.

In the rest of this chapter, we introduce a new routing approach which is well adapted to vehicular ad hoc networks called Road Connectivity-based Routing (RCBR). Based on the fact that the density of vehicles moving along one road is not an accurate indicator of its connectivity, RCBR defines the concept of road connectivity to provide real-time view of the network topology. In addition to providing a good support for delay sensitive applications, RCBR has the advantage of performing well under sparse networks. A detailed description of the proposed scheme is given on the following section.

4. New approach: road connectivity-based routing protocols

RCBR routing approach combines information about the real-time vehicular traffic and the road-topology to select more stable routing paths. The idea is mainly based on the concept of road connectivity describing the state of each road segment whether it is connected or disconnected. In this context, a road is defined as connected if it has enough vehicular traffic which allows the transmission of the packet through multi-hop communications between its two adjacent intersections. For that, we define an algorithm predicting the connectivity duration over each road segment.

We designed two variants of RCBR protocols: a source routing protocol S-RCBR and a dynamic version of D-RCBR. S-RCBR computes the route using a global connectivity graph of the real-time state of the road segments and includes them in the packets. In D-RCBR, dynamic routing decisions are executed only in the proximity of road intersections to select a next segment through which data packets will be forwarded.

This class of protocols assumes that each car is equipped with a Global Positioning System (GPS) to get its own position and a navigation system that provides information about the local road map. In addition, the current position of a destination node is discovered by mean of location service. The road topology is mapped into a graph, $G(V, E)$ where V is the set of vertices representing the road intersections and E is the set of edges representing the segments of road connecting adjacent vertices.

4.1 Road-connectivity model

In this subsection, we present the mathematical model used by RCBR routing protocols to estimate the connectivity of each road segment. First, we introduce some definitions that serve to this illustration and will be used throughout this chapter. Then we describe the prediction model.

1. **Intersection virtual range:** in this context, the range of a road intersection is defined as the area within the circle centred on it and which radius is half of the wireless communication range. This value is delimited to the half of the transmission radius to ensure that the distance between any two vehicles in this area is less than the radio range and hence they can communicate.
2. **Link duration (LD):** the link duration between two vehicles represents the period during which they remain within the transmission range of each other. It can be

estimated by applying the mobility prediction method presented in [Su et al.,]. If we consider, two vehicles N_i and N_j , with a transmission range R , speeds v_i and v_j , coordinates (x_i, y_i) and (x_j, y_j) , and velocity angles θ_i and θ_j , respectively, the Link Duration $LD_{i,j}$ is predicted by:

$$LD_{i,j} = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)r^2 - (ad - bc)^2}}{a^2 + c^2} \tag{1}$$

Where

$$\begin{aligned} a &= v_i \cos \theta_i - v_j \cos \theta_j \\ b &= x_i - x_j \\ c &= v_i \sin \theta_i - v_j \sin \theta_j \\ d &= y_i - y_j \end{aligned}$$

Through the beacon messages periodically exchanged between neighboring nodes, each vehicle maintains a table of its neighbours' information which uses to compute their corresponding link durations [17].

3. **Path Connectivity (PC):** the path connectivity CP_i of a multi-hop path P_i formed by $n-1$ links connecting n neighboring vehicles N_1, N_2, \dots, N_n is defined as the duration for which all the links are still available. It is called also lifetime and can be formulated as:

$$CP_i = \min(LD_{N_j, N_{j+1}}) \tag{2}$$

Where N_i and N_{j+1} are two successive nodes of P_i .

4. **Road Connectivity (RC):** A road segment is said to be connected if there is at least one multi-hop path connecting its two adjacent intersections. To estimate the connectivity over one road, we exploit the concept of path connectivity. In this context, a path between two adjacent intersections I_i and I_j is defined as a multi-hop path formed by links between neighbor vehicles moving on the road segment delimited by these intersections and connecting two vehicles situated on virtual range of I_i and I_j respectively. Figure.3 shows an example of a path between two adjacent intersections I_1 and I_2 .

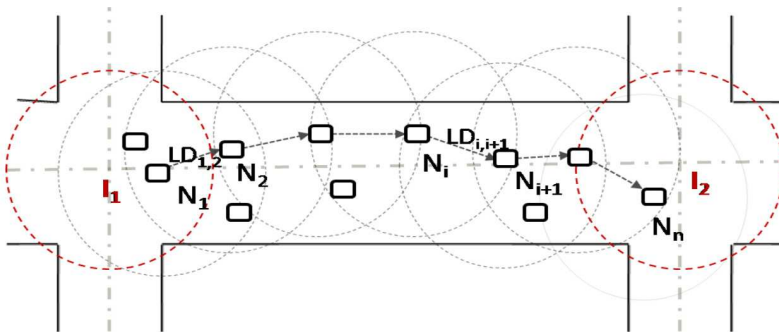


Fig. 3. A connected road segment delimited by intersections I_1

As a consequence, the Road Connectivity of a segment $[I_i, I_j]$ can be formulated as the highest Path Connectivity of all the paths P_i between the adjacent intersections I_i and I_j . It is computed by the following formula:

$$C_{Pi} = \max(C_{Pi}) \{ \forall P_i \text{ path connecting } I_i \text{ and } I_j \} \quad (3)$$

In practice, a vehicle directly connected to one intersection computes the period during which it remains in its virtual range and inserts it in its hello message. Through the propagation of the beaconing messages, all vehicles in this road are then able to estimate their connectivity to both intersections delimiting the road segment. Only the vehicles in the proximity of the intersection maintain a connectivity table containing the information about all the adjacent intersections. This table is updated based on the information exchanged between different vehicles in the proximity of the intersection.

4.2 S-RCBR: source routing protocol

RCBR is a source routing protocol that proactively computes paths between the source and the destination using the connected road segments. Based on the road connectivity model described above, it defines a global real-time graph called "Connectivity Graph" to maintain a consistent view of the network connectivity. The connectivity information is exchanged between vehicles and a server deployed on the roadside infrastructure using V2I communications. Each source uses the road segments marked as connected to compute an optimal stable path which is then stored in the header of data packets to be used for geographic forwarding.

4.2.1 Network connectivity discovery

To optimize the routing decisions using the support of the infrastructure, we suggest deploying a Connectivity Server (CS) integrated to the roadside infrastructure and able to communicate with the vehicles through V2I communications. The CS aggregates all the connectivity information received from different vehicles in order to build a Connectivity Graph describing the state of all the road segments in the nearby zone.

Therefore it maintains a table with entries of the form

$$\langle I_{begin}, I_{end}, Duration, T_s \rangle \quad (4)$$

where I_{begin} and I_{end} indicate the two adjacent intersections limiting the road segment, $Duration$ represents the connectivity period calculated at the instant T_s .

In order to reduce the data traffic managed by the server, only some particular vehicles transmit Connectivity Packets (CP) to the server. In fact, after predicting the connectivity of the road segment using the model described below, the nearest vehicle to the intersection sends a CP to the server and notifies its neighbors by adding into the next hello message.

Further, the CP initiation time is known by all the vehicles located on the range of the intersection and only one CP is sent per intersection. As a consequence, the server receives a connectivity packet from each intersection; note that it is possible to receive multiple CP related to the same road from different nodes present in both intersections defining the segment.

On the reception of each CP, the server updates the corresponding entry in the connectivity graph. Once the graph is rebuilt, it can be transmitted on-demand to different nodes present in the zone. To give an overview of the above process, figure 4 illustrates an example of the server updates and the form of connectivity graph created for the road structure.

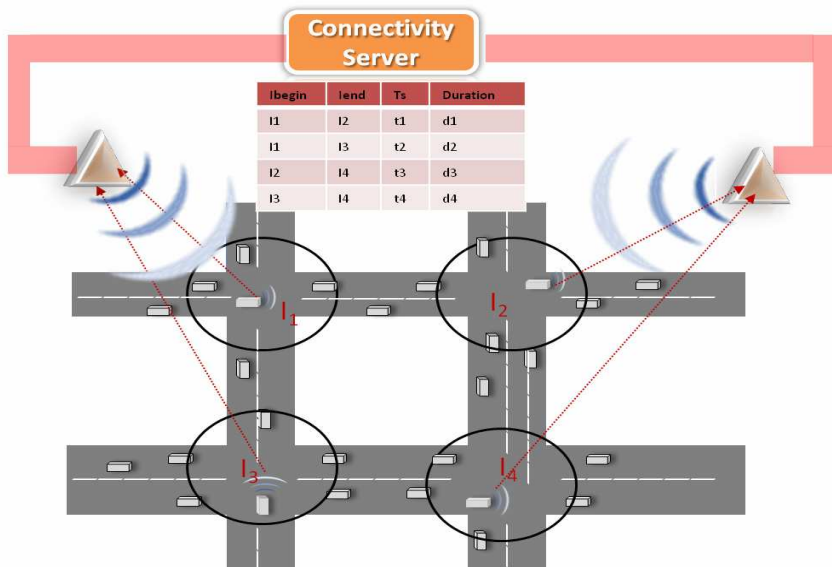


Fig. 4. The Connectivity Graph (CG) is constructed using connectivity packets (CP) sent by the nearest vehicle to each intersection.

4.2.2 The routing algorithm

In S-RCBR, the routing process consists of two main tasks: 1) defining the routing paths through which the packets will be forwarded and 2) forwarding data packets along the selected path using the greedy forwarding.

S-RCBR uses road-based paths consisting of sequence of intersections to transmit the data packet through connected road segments. When a source node needs to send information to a given destination, it initiates a CRequest to obtain the connectivity graph from the server. Based on the newly received graph, a routing path with most stable routes is constructed along the segments with the highest connectivity. These routes are stored in the headers of the data packet to be used by intermediate nodes while transferring packets between intersections denoting the defined path. In between intersections, the greedy forwarding is used.

To maintain fresh information about the network connectivity, a data source periodically generates a CUpdate to get the latest information from the server. The routing paths are updated accordingly using fresher information.

Finally, since network partitions cannot be avoided in highly dynamic environment like VANET, S-RCBR uses the Carry-and-forward strategy. Indeed, to handle network disconnections, packets are buffered and later forwarded when an available next hop is found to restore the connection.

4.3 D-RCBR: dynamic routing protocol

D-RCBR is a dynamic variant of RCBR that only requires a local view of the road connectivity, since collecting global real-time information about the entire network can be expensive especially with the mobility of vehicles. The new protocol performs local routing decisions only near road intersections. It uses the road connectivity prediction model

described in the section above to estimate the connectivity over each road segment. Through the propagation of the beaconing messages, all vehicles moving along a given road are able to estimate the expected time for which they remain connected to both intersections delimiting the road segment. Then, this connectivity information is gathered near each intersection thanks to the dissemination mechanism based on the exchange of HELLO messages between different vehicles in the proximity of the intersection. Therefore, each vehicle located inside the virtual range of an intersection maintains a local connectivity table with entries about all the adjacent intersections. Based on this local connectivity information, the vehicles make the routing decisions and select the next vertex towards the destination. The idea of the greedy scheme is applied to select the closest intersection to the destination only among the adjacent connected intersections. However, the packets can reach an intersection which has no adjacent intersection closer to the destination. This situation known also as a local maximum is likely to happen considering only a greedy selection of vertex. To address this problem, D-RCBR defines a recovery procedure inspired from the right hand rule (Karp & Kung, 2000).

The routing process includes two main tasks: 1) Select the next intersections towards the destination using one of the two strategies: Greedy or right-hand rule for the vertex selection 2) forward data packets hop by hop towards the selected intersection.

1. Greedy Vertex-Selection: In this mode the idea of the greedy scheme is applied to select the closest intersection to the destination among all the adjacent connected intersections. When a packet reaches a vehicle in the range of an intersection, the vehicle selects the next intersection towards the destination. Only a connected adjacent vertex can be selected to ensure the delivery of the packet along the forwarding road. However, to minimize the networking delays, the closest intersection to the destination is chosen. To do so, all the neighbor vertices which are disconnected from the current vertex are removed from the road graph G and then the shortest path between the current vertex and the destination is computed using Dijkstra algorithm. The next intersection in the determined path is inserted into the packet header. Between two intersections the greedy forwarding scheme is used to forward the packet. An example of packet routing with the proposed D-RCBR is shown in Figure 5 where a source node S has a packet addressed to the destination D . S is in the proximity of the intersection I_1 so the shortest path should be computed from intersection I_1 to the destination near the intersection I_6 . By exploiting the local connectivity information gathered by the nodes near I_1 , the intersection I_2 is marked as unreachable and is not considered for the shortest path computation. As a consequence, the closest vertex to the destination among all the adjacent connected vertices is selected as the next intersection. The greedy vertex selection is repeated until the packet reached the intersection I_6 as one of the destination's road. In the figure, the disconnected roads are marked by a cross.

2. Right-Hand rule for Vertex Selection: Using the greedy selection of vertex, D-RCBR helps reducing the overhead needed by a global knowledge of the network connectivity. However, there is no guarantee for the packets to be delivered until the destination. An example is shown in Figure 6 when a packet reaches the range of intersection I_5 and the adjacent intersection I_6 which represents the destination vertex is disconnected. As a consequence, the greedy selection fails although a possible path exists between I_1 and I_6 . To address the aforementioned problem, we suggest using the idea of the right hand rule to select an intersection in counter clockwise. This idea was previously adopted by GPSR, but contrary to GPSR, in D-RCBR the right hand rule is applied to the road graph where vertices are intersections instead of the network graph where vertices are mobile nodes.

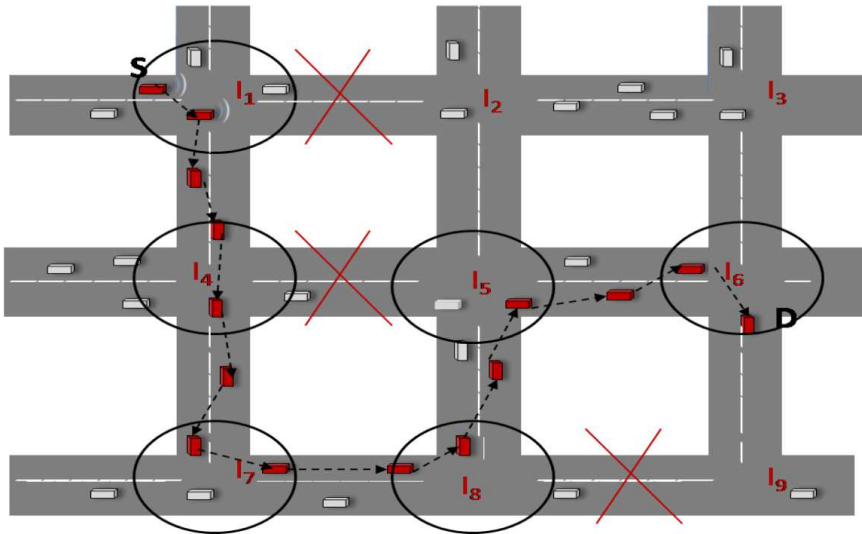


Fig. 5. The greedy strategy applied for the vertex selection in D-RCBR

Hence, if the greedy selection of intersection fails, the forwarding node in a range of an intersection selects, following the right hand rule, a next vertex among the connected neighbor vertices. The protocol should returns back to the greedy selection of vertex as soon as the packet escapes from the local maximum. With this procedure, D-RCBR can ensure finding a possible path to destination if any exists.

To illustrate the recovery procedure described above, a scenario of the failure of greedy selection is described in figure 6 using the same road topology. A data packet reaches the

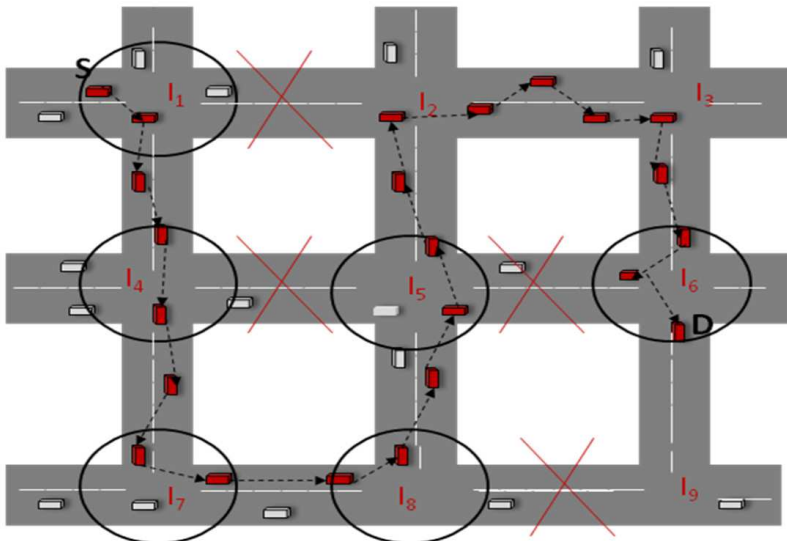


Fig. 6. The right hand rule for vertex selection

range of intersection I_5 where a local maximum occurs since no adjacent connected intersection is closer to the destination. D-RCBR switches to the recovery mode and selects according to the right hand rule the vertex I_2 as next vertex. The packet is sequentially forwarded through the intersections I_3 and I_6 where it can be delivered to the destination.

4.4 Simulation and analysis

In order to evaluate the proposed solution, an implementation two variants of RCBP protocols has been developed under Network Simulator (NS2). The simulations were carried out with different nodes densities and velocities. The results were then compared with those achieved by three other existing protocols: GPSR, GSR and CAR.

In particular, we were interested in comparing two main metrics: the packet delivery ratio and the average end-to-end delay.

In the following subsections, we describe the simulation environment and present a detailed analysis of the results.

4.4.1 Simulation environment and setup

The simulations have been performed for a vehicular mobility scenario in city environment. The road topology is based on a real map extracted from TIGER (Topologically Integrated Geographic Encoding and Referencing) database. The mobility traces of vehicle movement were generated using a realistic vehicular traffic generator VanetMobiSim (Härri et al., 2006). Vehicles move along the streets with speed limits equal to 50km/h and they change their directions at road intersections. The key parameters of the simulation are summarized in table1.

Simulation parameter	Value
Simulation time	600s
Map size	2500 x 2500 m ²
Number of roads	39
Number of road-intersections	33
Number of vehicles	150
Vehicle velocity	15-50km/m
Wireless transmission range	250m
Beacon interval	1s
Data packet size	512bytes

Table 1. The simulation parameters

4.4.2 Packet Delivery Ratio

One of the metric used to evaluate the performance of a routing protocol is the packet delivery ratio (PDR). It is computed as the ratio of the total number of packets received by the total number of packets transmitted by different source nodes.

The graph in Figure 7 shows the average delivery ratio varies as a function of the packet generation rate obtained by varying the sending interval for the different studied protocols. GPSR considers neither the road topology nor the vehicular traffic and hence packets are more likely to encounter a local maximum which explain the low delivery ratio. On the other hand, GSR improved the forwarding decision with spatial awareness as the sequence

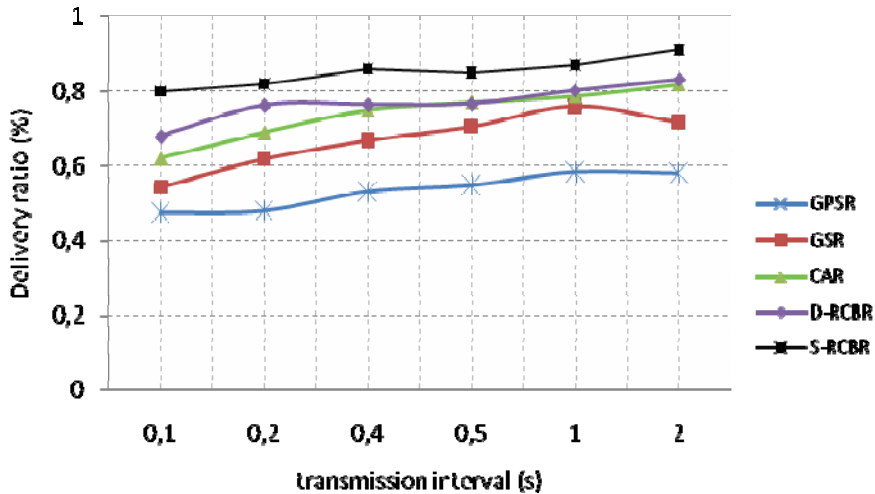


Fig. 7. Packet Delivery ratio Vs Packet sending interval

of junctions is computed before data forwarding. However, since the path is determined without considering real-time traffic, some packets fail to reach their destination when being forwarding along non connected streets which explain the obtained success delivery rate.

The proposed S-RCBR protocol demonstrates the highest delivery ratio than other protocols. This is because the real time traffic information guaranties the connectivity of the entire selected path. Hence, packets are forwarded along connected paths. Moreover, networks partitions are avoided and fewer packets are suspended. Nevertheless a disadvantage that can be noted in S-RCBR is the need for roadside infrastructure which can be costly and not always possible.

The figure depicts also that the number of successfully received packets in D-RCBR are comparable with CAR and even with a relative improvement. The advantage of D-RCBR is that, contrary to S-RCBR and CAR no global knowledge of the network traffic density or real-time connectivity is assumed. The path is dynamically determined following the local connectivity information available in crossroads. So, a packet is only forwarded along connected roads that successfully lead to the destination. Hence, D-RCBR adapts to frequent networks changes.

4.4.3 End-To-end Delay

The results presented in Figure 8 show that S-RCBR achieves a lower end-to-end delay compared to the rest of the protocols (GPSR, GSR, D-RCBR and CAR). The main reason is that S-RCBR offers an accurate view of the network that helps a source node to select a connected path reducing so the chance of facing network disconnections. The packets are simply forwarded along a pre-computed path following the greedy scheme which decreases the networking delays.

GSR does not consider the vehicular traffic to guarantee the connectivity of the shortest path and that is why more packets are likely to be suspended and buffered. CAR also may select

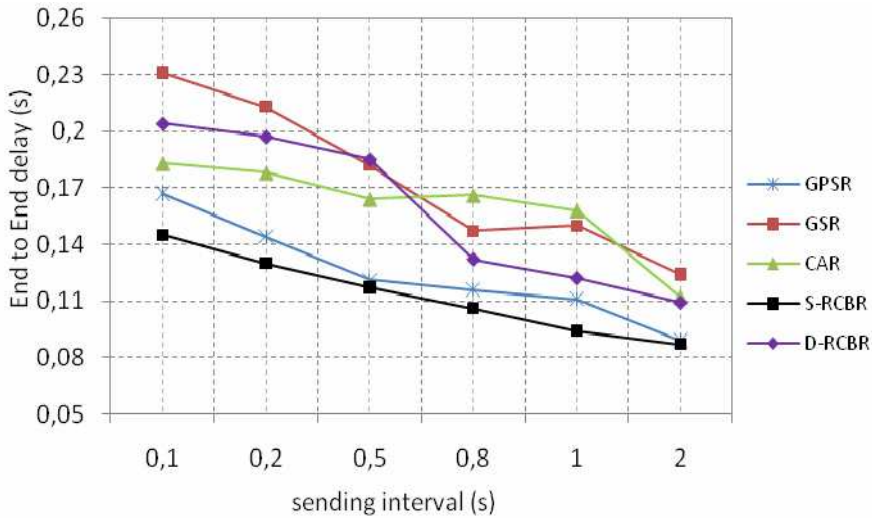


Fig. 8. The end-to-end delay of different protocols

a non optimal path due to the error in the road density information that affects the estimation of the probability of connectivity.

In its turn, D-RCBR achieves a lower end-to-end delay compared to GSR and its performances are as good as CAR. In D-RCBR approach, the routes are discovered while relaying the packet so that the probability of route breaks is much reduced during the forwarding delay. However, CAR uses a source routing approach and generates an additional overhead for the density estimation.

The delay remains higher in D-RCBR than in GPSR because the packets which are usually dropped in GPSR when the perimeter mode fails to handle the local maximum frequently encountered in city environments; they are successfully delivered with D-RCBR mechanism. Note that both D-RCBR and S-RCBR provide an average latency less than 240 ms which proves that the proposed scheme meets the requirements of delay sensitive applications with a good tradeoff between the delivery ratio and the end-to-end delay.

5. Conclusion

Throughout this chapter, we have analyzed the routing problem in vehicular ad hoc networks and presented a taxonomy of existing protocols.

Several routing protocols have been proposed or adapted for the vehicular applications. Nevertheless, the geographic routing has become the trends taking advantages of the availability of navigation system that makes the vehicle aware of its own location as well as its surrounding. Many studies showed that the exploitation of the road-topology improves the routing performances especially with complex mobility patterns of vehicular environments. Also the use of traffic information is proved to be of a great importance and demonstrated better performances. Different ways are used to model this traffic awareness through the historical density data or the real-time traffic information.

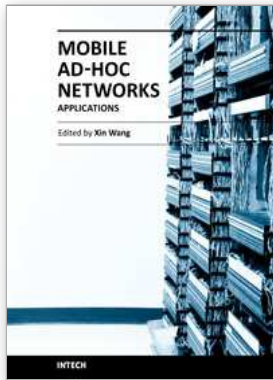
In this chapter, we proposed two routing protocols S-RCBR and D-RCBR that combine both the road topology and the real-time traffic. RCBR protocols define a prediction model to

estimate the connectivity along the road segments. Then based on this connectivity information either a source route is computed as a sequences of intersection along the connected roads or the path is dynamically adjusted at each intersection. Geographical forwarding is used to transfer the data packets between the vehicles along the road segments that form these paths. The simulation results showed that the proposed protocols outperforms existing approaches and provide a good support for vehicular scenarios. In particular, D-RCBR can be used for vehicular applications where throughput is the main requirement while S-RCBR is suitable for delay-sensitive applications.

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Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: vehicular ad-hoc networks, security and caching, TCP in ad-hoc networks and emerging applications. It is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.

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