Understanding Geographic Routing in Vehicular Ad Hoc Networks

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Abstract—**Geographic routing in Vehicular Ad hoc Networks (VANETs) has recently received considerable attention. Developing multi-hop communication in VANETs is a challenging problem due to the rapidly changing topology and network disconnections. These problems result in failures or inefficiency in traditional routing protocols used in Mobile Ad hoc Networks (MANETs). With the widespread adoption of Global Position System (GPS) and the progress on self-configuring localization mechanisms, geographic routing protocols offer promising solutions for message delivery. In this paper, we present an overview of geographic routing strategies in vehicular ad hoc networks. In addition, we introduce the main challenges of using geographic routing protocols in VANETs from different perspectives and discuss some directions of future research on this field.**

Keywords-**Geographic Routing Protocols; Geographic Information Systems; Vehicular Ad Hoc Networks**

I. Introduction

Mobile ad hoc networks (MANETs) are self-configuring and self-organizing multi-hop wireless networks, composed by a set of mobile nodes that move around the network and cooperate in transmitting packets among the nodes. A MANET performs efficient and robust procedures by providing routing functionalities for mobile nodes. For instance, a unicast routing creates a multi-hop forwarding path for a pair of source and destination nodes beyond the direct wireless communication range. In addition, routing protocols maintain connectivity if the links on the paths break due to some problem, such as radio propagation, node movement, or wireless interference.

In MANETs, the velocity of a mobile node is probably equal to that of a walking person. If mobile nodes are vehicles, these networks are called Vehicular Ad Hoc Networks (VANETs). Compared with MANETs, the velocity of vehicles in VANETs is much higher since vehicles move faster than walking persons [1]. The main motivation to study routing protocols in VANETs is related to the expansion of data exchange among vehicles in order to provide robust applications for Intelligent Transportation Systems (ITS). VANET applications can include on-board active safety systems, providing communications among nearby vehicles (V2V) and between vehicles and the roadside infrastructure (V2I). However, several challenges have been identified to adopt VANET utilization on a large scale. The challenges are usually associated with the high node mobility, dynamic scenarios and the scalability considering the number of nodes. Therefore, it is important to develop a robust routing protocol to provide an efficient communication among nodes.

Currently, there are mainly two types of routing protocols in VANETs: topological routing and geographic routing. In topological routing, mobile nodes use topological information to manage routing tables or search routes directly. In geographic routing, each node knows its own position and makes routing decisions based on the position of the destination and the positions of its local neighbors [2]. With the widespread adoption of Global Position System (GPS) and the progress on self-configuring localization mechanisms, geographic routing in VANET has garnered significant attention to provide promising solutions for message delivery.

In spite of the existence of a considerable number of papers about geographic routing in mobile ad hoc networks (MANETs) [3] [5], we perceived a lack of a specific overview involving the use of geographic routing protocols in vehicular ad hoc networks (VANETs). This paper then presents an overview of general concepts of geographic routing in vehicular ad hoc networks. In addition, we introduce the main challenges of using geographic routing protocols in VANETs from different perspectives and discuss some directions of future research on this field. The remainder of this paper is structured as follows. We first introduce basic concepts of geographic routing and present some general goals for designing a routing protocol in VANETs. We then present the geographic routing protocols available in the literature, followed by a discussion about these protocols. Finally, we indicate some possible directions of future research and conclude the paper.

II. Basic Concepts of Geographic Routing

Although the research on geographic routing being more recent than topological routing, it has received a special attention due to the significant improvement that geographic information can produce in routing performance. Geographic routing can be defined as a type of stateless routing, in which it is not required that a node performs maintenance

functions for topological information beyond its one-hop neighborhood [6]. Consequently, geographic routing is more feasible for large-scale networks than topological routing, which requires network-wide control message dissemination. Besides that, geographic routing requires lower memory usage on nodes by maintaining the information locally.

In general, geographic routing is composed of two main components: a location service and a geographic forwarding process. The location service determines the position of the packet destination in order to improve the routing process for creating the path with source node, using intermediary nodes. Consequently, the position of the packet destination can be added in the packet header so that intermediate hops can know where the packet is destined for [7].

Likewise, geographic forwarding is performed in two modes, namely, geographic greedy-forwarding mode and void-handling mode[1]. The greedy-forwarding mode defines a next-hop node for packet forwarding taking into account the positions of the current node, its neighboring nodes, and the destination node. A node can obtain its own position via a GPS receiver or through other localization algorithms. The positions of the neighboring nodes can be acquired either from a centralized neighborhood table at the node or in a distributed method via contention among neighboring nodes [10]. At last, the position of the destination node is included in the packet header sent by the source node. However, if some intermediate node knows a more accurate position of the destination, it is able to update the position in the packet header before forwarding the packet.

Geographic routing protocols offer some advantages over traditional ad hoc routing strategies. First of all, the geographic forwarding process allows the path adaptation by selecting the best next hop, if an intermediate node, previously used, becomes unavailable. Due to the absence of a routing creation process, this path selection does not need a table maintenance procedure other than intermediate neighbors and the propagation of control packets. Other advantages are related to the capacity to utilize weight additional metrics in order to select the next hop and the route alteration node by node taking into account the QoS related to the neighbors, such as bandwidth and delay [11]. However, some challenges in geographic routing are still open and need to be investigated [12].

- The difficulty to control the overhead required for distributed location database service of geographic routing protocols. Although location based addressing offers a convenient, naturally occurring, hierarchical address structure in terms of name, city, state and country, it may lead to excessive control overhead in conditions of high mobility.
- The irregular distribution of vehicles on urban centers

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[1]Sometimes it is called the back up mode or recovery mode in the literature [7] [9]

makes route selection more complex, e.g. the shortest path protocols may produce more frequent network disconnections.
- High signal interference in the communication due to the presence of large buildings. Therefore, a building or lack of radio coverage can result in voids in the physical network topology. These voids can obstruct the packet forwarding process at local minima, where the neighbors close to the destination are hidden/unreachable, resulting in a failure.

In summary, the process to compute the best routes to send packets in Vehicular Ad hoc Networks (VANETs) is a difficult task due to high node mobility and the existence of unstable wireless links. To improve the performance of geographic routing protocols, several solutions were created. We present an overview of the main proposed techniques for geographic routing and appoint the main challenges of using geographic routing in vehicular ad hoc networks.

III. GEOGRAPHIC ROUTING IN VEHICULAR AD HOC NETWORKS

Ad hoc routing protocols have to provide routing procedures to select the best routes in order to send packets from a source node to a destination node, taking into account the utilization of multiple hops. In the same way, geographic routing protocols can use location services to improve these procedures. Figure 1 shows a general architecture of geographic routing in VANETs.
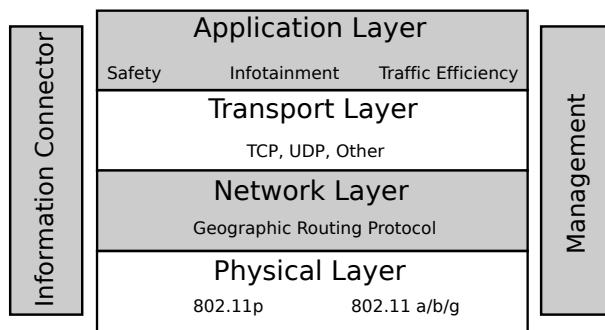

Figure 1. Geographic routing architecture for vehicular ad hoc networks.

As we can observe, a general architecture of geographic routing in VANETs is composed of four main layers and two additional modules to treat the geographic information. The architecture could be seen as a top-down approach. The first layer is named *Application Layer*, which is used to offer VANET applications as interfaces between users and communication layers. The *Transport Layer* can operate using traditional transport protocols (i.e. TCP or UDP) as well as specific transport protocol for VANETS (i.e. Car-2-X [13]). In the *Network Layer* we find the services and procedures provided by the geographic routing protocol, such as the location services and the forwarding procedures. The last

layer is the *Physical Layer*, which can be operational using conventional wireless communication protocols (i.e. IEEE 802.11a/b/g) and VANET wireless communication protocols (i.e. 802.11p [14]).

Besides that, additional modules are vertically added in the left and right sides of the architecture, namely, *Information Connector* and *Management*. The *Information Connector* operates as a cross-layer approach to support efficient and structured information exchange across the layers. Likewise, the *Management* module is able to manage this information for improving robustness and reliability of packet delivery in vehicular communication.

In spite of the existence of these layers and modules, our focus in this paper is related to geographic routing protocols in VANETs. Therefore, we continue presenting the services and procedures contained in the *Network Layer*. As previously explained, a geographic routing protocol is generally consisted of a location service and a geographic forwarding strategy, which are described in the Sections IV and V.

IV. LOCATION SERVICE

Kasemann et al. [15] introduced an example of location service, which was called Reactive Location Service (RLS). When the source node executes the RLS, it sends a message to discover the position of the destination, containing the identification of the destination node in addition to its identification and position. The message is flooded in the network until the destination is reached or the Time-To-Live expires. At the moment that the message is received by the destination, a response of localization is sent to the source node, containing the position of destination node [16].

In [17], the authors presented the Vehicle Location Service (VLS) protocol, a map-based vehicle location service for city environments. In summary, the information in digital maps is used to perform location service. They present a new method of partitioning the network and constructing distributed location servers.

Another strategy to put in practice the location service can be provided by cellular and infrastructure networks, where each node notifies its position to a specific server that stores location information for a set of nodes. In the proposal presented in [18], each node initially communicates to each other one of its current location. The server for a node is defined as the set of nodes located within a circle of limited radius, centered at its initial position. Before sending a location update message the node geocasts such a message to its server. In other words, the location update message is unicasted using geographic routing until it reaches one node inside the server. This message is then disseminated inside the server's circle. When the destination node is found, the source node sends out two search messages. The first is oriented to the last known position of the destination, and the second is forwarded in direction of the destination's server.

When the search message arrives at the destination or a node within the server, the source is notified with the current location [19]. Once the destination's position is known, the geographic routing protocol initiates the geographic forwarding.

V. GEOGRAPHIC FORWARDING

As previously described, geographic forwarding algorithms work in two different modes: greedy mode and void-handling mode. The principal difference leads in determining the situation where it is convenient to use each. The greedy forwarding mode is used whenever possible, and the void-handling mode is strictly used when the greedy forwarding mode cannot be applied.

A. Greedy Forwarding

Several greedy-forwarding algorithms perform different optimization techniques to select the next-hop node closest to the destination node. Face routing [20] is one of the fundamental algorithms for routing packets using compass routing on geometric networks. The key idea is to select the best path along the faces intersected by the line segments between a source and a destination. To avoid loops using face routing, it is required a planar graph of the original network. A planar graph can be defined as a sub graph without crossing edges, which represents the same connectivity as the original network. Therefore, face routing guarantees to reach the destination after as long as the network topology is a planar graph [21].
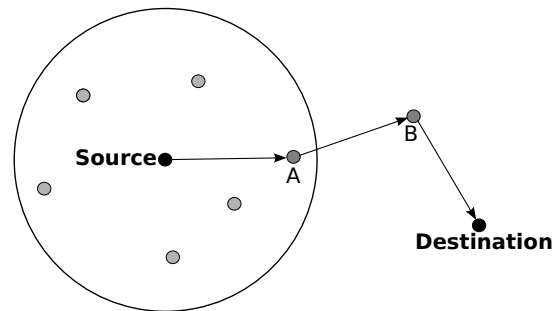

Figure 2.   Greedy forwarding mode.

Figure 2 shows an example of the greedy forwarding mode. As we can observe, the *Source* node sends a message to the *Destination* node. Once the location service detects the node positions, the greedy routing algorithm selects the next-hope closest to the destination, for example, the node *A*. Then, the node *A* chooses the next-hope using the same selection rules until the message reach the *Destination* node. When a node cannot locate the next-hope node, it can use the void-handling mode [7]. In this model, the node decides to route the packet around the void since there is a possibility that a valid path from the source to the destination node exists.

B. Void-handling Mode

The void-handling mode is strictly applied as a recover strategy to deliver packets when the greedy forwarding mode cannot be used due the existence of communications voids. As cited in the Section II, a void occurs as a result of high signal interference in the communication due to the presence of large buildings. These buildings or lack of radio coverage can result in voids in the physical network topology. Therefore, voids can obstruct the packet forwarding process at local minima, where the neighbors close to the destination are hidden/unreachable, resulting in a failure.

Communications voids are considered as a serious problem for any feasible geographic routing protocol. It is important to know how to handle voids in an effective and efficient manner. Besides that, it is a difficult task to predict when and where a void will occur due to the unpredictable patterns of node deployment and the uncertain dynamics of time varying wireless network environments. Thus, data packets can be lost in the network if a robust void-handling strategy is not implemented, wasting network resources as well as disabling communications between pair of nodes.
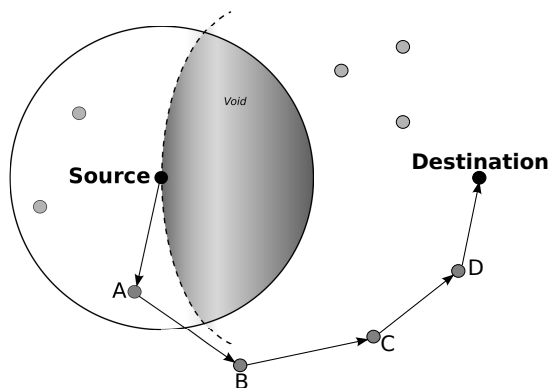

Figure 3.   Void-handling mode.

Figure 3 presents an example of void-handling technique due to occurrence of a communication void. According to the example, a *Source* node desires to send a packet to *Destination* node. However, the *Source* node is closer to the *Destination* than any of its neighboring nodes that are located within its radius. Consequently, it is not possible to send a packet using the greedy forwarding mode. In this case, the packet is said to have encountered a communications void and can be sent by the path (*A - B - C - D*). Finally, the *Source* node is called a void node while the shaded region, without any nodes inside, is a void area.

The simplest void-handling strategy is *flooding* the network from the *Source* node to all neighboring nodes. If each node executes the same procedure, this strategy will certainly enable the packet to reach the *Destination* node when at least a path is found. However, this strategy is effective but inefficient in relation to resource utilization, since each node

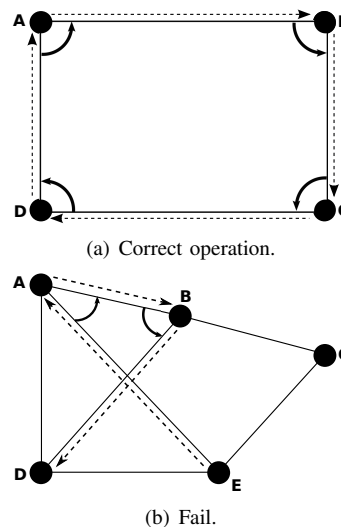(a) Correct operation.

(b) Fail.

Figure 4.   Right Hand Rule.

has to forward the packet and the *Destination* node may receive many copies of the same data packet from different paths.

VI. Challenges of using geographic routing in VANETs

There are several prerequisites on the availability of position information in VANET environments, such as position-awareness of each participating vehicle, e.g., a GPS receiver installed on every vehicle. However, this assumption of using position systems is possible due the multiplication of Global Position System (GPS) and the progress on self-configuring localization mechanisms in urban scenarios. Thus, it is important that each vehicle be aware of each neighbor position. A way to perform the position updates is sending beacon messages that indicate the current position of the vehicle.

The Greedy Perimeter Stateless Routing (GPSR) protocol is one of the most important algorithms to demonstrate the basic concepts of geographic routing in vehicular ad hoc networks. There are several proposals that use GPSR models to offer new geographic protocols in VANET scenarios, such as [22] and [23]. In summary, the GPSR is a purely local decision strategy, since no route setup or maintenance is required. Instead, forwarding hops are determined 'on the fly' [2]. It applies both greedy forwarding to send packets using position information and a void-handling technique through the perimeter mode as a recover strategy when the greedy forwarding fails. In such a case, position information points in the right direction but is not correlated with available paths to the destination.

Two void-handling techniques are used in the perimeter mode of GPSR protocol. The first technique is similar to an online routing algorithm for planar graphs and the second
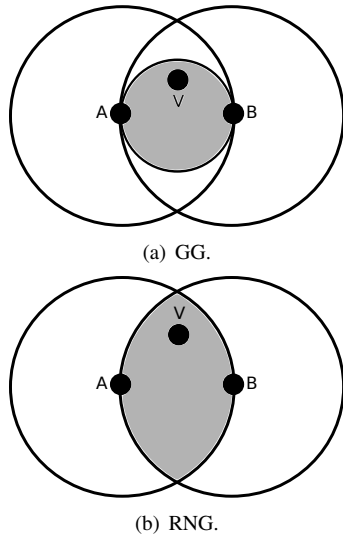
(a) GG.

(b) RNG.

Figure 5.   Gabriel Graph (GG) and Relative Neighborhood Graph (RNG).

is a distributed planarization algorithm. The algorithm for planar graphs is applied using the Right Hand Rule as presented in Figure 4. As we can observe in Figure 4(a), if a packet starts from the node *A* in direction to the node *B*, the next node will be *C*, following the edges *(A,B)* and *(B,C)*. Thus, the complete in the graph is $A \rightarrow B \rightarrow C \rightarrow D \rightarrow A$. The use of planar graphs is a good strategy for recovering the local maxima problem[2]. By definition, the planar graphs take into account those pairs whose edges do not cross or intersect in the plane. However, in the example presented in Figure 4(b), the graph that represents the VANET scenario is not a planar graph. Consequently, the GPSR utilizes a planarization algorithm.

According to Figure 4(b), if the path starts in the edge *(E,A)* and the Right Hand Rule is applied, the path will be composed by $E \rightarrow A \rightarrow B \rightarrow D$. Therefore, the node C is not reached. Two planarization algorithms are utilized in the GPSR: Relative Neighborhood Graph (RNG) and Gabriel Graph (GG) [24]. In summary, they perform removing algorithms to generate connected RNG and GG graphs. Based on Figure 5(a), a GG occurs if an edge (A, B) is found and there are not other vertices with diameter equal to the distance between A and B as well as do not cross these two vertices. On the other hand, if we observe Figure 5(b), a RNG graphs occurs when an edge (A, B) is found and the distance between A and B is minor or equal to the distance among a vertex V and A or B. Hence, we can conclude that a RNG graph is a sub graph of a GG graph.

The use of planarization algorithms in vehicular ad hoc networks allows performing the Right Hand Rule due to the elimination of crossing edges. However, the elimination algorithm can remove essential nodes in the VANET

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[2]This problem occurs when the *Source* node is closer to the *Destination* than any of its neighboring nodes that are located within its radius.

scenario, which can result in the network disconnection. Other problem of using planarization algorithms is related to the excessive number of hops. For example, a vehicle can directly send a packet to the destination, but it sends to the next-hop most close to the destination. Other problems are associated to routing loops and wrong directions. The routing loops occur, for example, when a source node is in the right side of its two-hops neighbor node in the graph. Likewise, the wrong direction problem is found when there is more than one routing alternative, resulting in the use of long routes to deliver the packets.

To avoid planar graphs problems, Lochert et al. created the Geographic Source Routing (GSR) [2]. The key idea is to use the information contained in digital maps to compute routes, which creates an overlay network. The route is calculated using the Dijkstra algorithm. Similarly to GSR, Tian et al. proposed the Spatially Aware packet Routing (SAR) [25]. They use an association among digital maps and graphs. The routing process is based on the source routing.

In [26] the authors presented a geographic routing to avoid routing loop problems in urban VANETs. GeoCross exploits the natural planar feature of urban maps without resorting to cumbersome planarization. Its feature of dynamic loop detection makes GeoCross suitable for highly mobile VANET. The same authors presented in [27] a new approach using delay and disruption tolerant strategies, which is a hybrid geographic routing solution enhancing the standard greedy and recovery modes exploiting the vehicular mobility and on-board vehicular navigation systems to efficiently deliver packets even in partitioned networks.

VII. CONCLUSION

With the widespread adoption of Global Position System (GPS) and the progress on self-configuring localization mechanisms, geographic routing in VANET has garnered significant attention to provide promising solutions for message delivery. The main motivation to study routing protocols in VANETs is related to the expansion of data exchange among vehicles in order to provide robust applications for Intelligent Transportation Systems (ITS). VANET applications can include on-board active safety systems, providing communications among nearby vehicles (V2V) and between vehicles and the roadside infrastructure (V2I). However, several challenges have to be overcome before application on a large scale.

This paper presented main geographic routing strategies in VANETs scenarios. It shows benefits of use location-aware routing and discusses strengths and weaknesses of those approaches. Finally, the issues that need further investigations in this area were discussed.

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