A Survey of Routing Protocols for Vehicular Ad-hoc Networks (VANETs)

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Abstract— The purpose of this paper is to provide a comprehensive study on routing protocols for Vehicular Ad-hoc Networks (VANETs). The characteristics of vehicular communications favour the use of position based routing. Enhancements have been proposed in order to use additional information such as navigation information in the routing decisions to further improve the performance of these protocols. However, position-based routing is faced with the *local-maximum* problem for which recovery policies have been proposed. The *carry-n-forward* mechanism is the most suitable for VANETs when end-to-end delay limits are not strict. Moreover, the requirements for Quality of Service (QoS) impose new challenges in routing which are not feasible to be solved using single layer information. Therefore, cross-layer approaches have been proposed to take into account the link or path quality using information from MAC and physical layer. Finally, every position-based routing protocol needs to know the position of the destination. This is achieved with the use of location services.

Index Terms—vehicular ad-hoc networks, position based routing, cross-layer designs, location services.

I. Introduction

Increasing interest by industry and academia on Intelligent Transportation Systems (*ITS*) over the last years has also promoted the research on vehicular communications. *ITS* aim to apply Information and Communication Technologies (ICT) to improve safety and efficiency as well as the passenger experience in modern transport systems [1]. It is envisaged that dynamic vehicular networks, particularly Vehicular Ad-hoc Networks (VANETs), will be an important part of the future *ITS*. Unlike traditional communication networks, VANETs are expected to be highly dynamic systems resulting in significant reliability issues for the communication protocols, routing protocols in particular. Some of the differences that distinguish VANETs from legacy Mobile Ad-hoc Networks (MANETs) are the followings. Contrary to MANETs that usually rely on batteries with restricted energy, VANETs lack strict energy constraints due to the power supply from vehicle's engine. The computational power and storage capacity are also larger than other MANETs, which enables developers to design more complex systems. A key characteristic of VANETs is the mobility of the nodes. Depending on the environment, one can have high velocities in straight roads like in highway environments, or lower speeds with frequent stops and turnings when moving inside cities. In contrast to random models that are used to describe the movement of MANET nodes, vehicles are restricted by the underlying road network, which makes it possible to predict their positions. Moreover, the environment

characteristics such as buildings and other vehicles oppose challenging conditions for the wireless communications. Finally, the density of the nodes varies over time which affects the connectivity of the network. Motivated by this, we give a summary of the existing routing protocols for VANETs outlining advantages and disadvantages.

It has been shown that using traditional routing protocols based on network topology is not efficient for dynamic ad hoc networks [16]. Therefore, position-based routing protocols have emerged. However, there are several concerns regarding these approaches. First of all, simply employing positioning information does not increase network reliability. To this end, enhancements have been proposed that take into account the mobility of the nodes as well as cross-layer information in order to increase network performance and Quality on Service (QoS). However, position-based routing is faced with what is known as *local-maximum* problem specially in low density networks. Therefore, the design should employ some policy to solve such cases. In addition, in position-based routing, maintaining and distributing position information is a non-trivial and important function. One possible answer to this challenge could be the use of location services aiming at providing solutions to such issues.

The rest of the paper is organised as follows. In section II we present a taxonomy of the routing protocols based on their forwarding mechanism pointing out the superiority of position-based routing in VANETs. In section III, position based routing protocols are presented. They are grouped in protocols that use navigation information and those that are not. Moreover, recovery strategies used to cope with the *local-maximum* problem are listed out. Section IV deals with cross-layer designs on network layer for better QoS utilizing link quality information. In section V we present several location services used by geographical routing protocols to get the position of the destination. Finally, in section VI we summarise our work, outlining challenges and the way forward in efficient and reliable routing in VANETs.

II. Routing protocols taxonomy for VANETs

Routing protocols can be categorized according to their forwarding mechanism as topology-based, hierarchical, flooding, and geographical (Fig. 1). Topology-based routing rely on the network graph that is composed by the nodes and the communication links between them. They are divided into proactive (table driven), such as OLSR [9] and DSDV

[43], and reactive (on demand) protocols, such as AODV [42] and DSR [22]. Proactive protocols introduce network overhead which increases as the size of the network topology is increased in order to keep their routing tables updated. On the other hand, reactive protocols add a delay in the beginning of the communication in order to discover a route whilst flooding the network with this query. Furthermore, the dynamic topology of a vehicular network will soon make the former route obsolete and thus a new query will be needed. There are also hybrid protocols, such as TORA [41] and ZPR [15], which combine characteristics of proactive and reactive protocols in different stages of their operation. Hierarchical protocols, such as HRS [17], divide the network into clusters, which share some common characteristics for a period of time. The inter-cluster communication is achieved through specified nodes which act as gateways. The aim of these protocols is the optimization of resource allocation but the dynamics of vehicular networks impose frequent changes on the clustering formation which in turn increases the overhead needed to maintain a cluster. The simplest way of disseminating a packet is to flood it in the network. This way, the complexity of the routing protocol is minimized but the overhead is exponentially increased. In order to use this kind of protocols in VANETs, several optimizations have been proposed to reduce the re-broadcasted packets but still the bandwidth is unfairly used.

The last category of routing protocols, geographical, is the one which best fits vehicular ad-hoc networks. The principle behind geographic routing is that forwarding decisions are made based on the position of the nodes and not on the network graph. Two fundamental assumptions are made in these protocols. First, that a node is able to know its own position. Such an assumption is valid since the use of GPS technology is widespread and every vehicle can be equipped with such a device. Apart from GPS, other means of positioning have been developed that can be used, like triangulation. The second assumption, and most significant, is that every node knows or is able to know the position of the destination when it is needed. This is achieved with two methods; either the use of location services such as HLS [24] that manages the position of all nodes or by broadcasting a query for the position of the destination, like topology-based on-demand protocols do when they initiate a communication, and wait for the destination to reply. It has to be mentioned that a proper neighbouring discovery mechanism has to be employed by geographic routing protocols that will provide accurate position information for the neighbours. The characteristics that favour geographical routing protocols in VANETs over the rest are the fact that they scale better in large networks since they only use localized information (only neighbouring information) to select the next forwarding node instead of the complete network graph that topology protocols need. Also, the routing overhead is less than flooding protocols since they only broadcast 1-hop beacon messages as a mean of neighbour discovery. Finally, compared with hierarchical protocols, geographical do not have the clustering overhead.
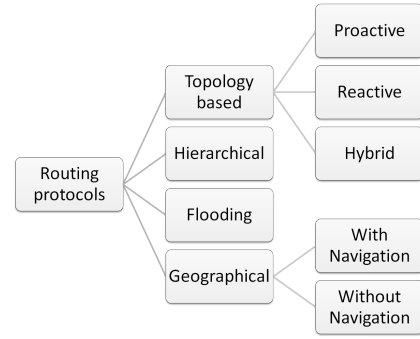

Fig. 1.   Routing Protocols Taxonomy

Thus, the use of geographical routing is vital in VANETs due to the highly dynamic topologies and the potential large number of nodes. However, the disadvantages of geographical protocols are that they rely on accurate positioning information from the location service and that they could potentially be faced with *local-maximum* problem.

III. GEOGRAPHIC FORWARDING MECHANISMS

Geographic routing was introduced in the 1980s [55] [13] but it was the increased use of positioning systems, like GPS, and the mobility of the nodes that brought them back to the foreground. The first protocols where designed for MANETs where nodes are randomly distributed and their mobility is relatively low. However, in VANETs, nodes travel on roads and navigation systems can provide additional information which could be used by routing. Therefore, it is appropriate to distinguish the forwarding mechanisms into two categories; those using only positioning information and those employing navigation as well. Finally, we define the *local-maximum* problem that geographic routing protocols are faced with and provide a summary of recovery mechanisms used to overcome this problem.

A. Forwarding without Navigation

In this section, we focus on unicast ad-hoc protocols using position information only as means of path selection, a legacy from MANETs. We try to answer the question how a node selects the next forwarding node based solely on geographically related information? We start with what is known as Greedy Forwarding (GF) [13]. With this method the next forwarding node is selected based on its geographic (Euclidean) distance from the destination. As shown in the example scenario of Fig. 2, in GF policy, source Node S will forward its packets towards Node #4 which is the closest node to the destination Node D. This policy is employed in several protocols such as GPSR [23] and in [13]. A different approach is to take the "Most Forward within Radius" (MFR) which is proposed in [55]. This scheme suggests that the node to be selected will provide the most forwarding distance on the direct line from the source towards the destination. This can be calculated using the cosine of the angle that is formed from a node, the source and the destination. In our example, $\cos \widehat{1SD}$ provides
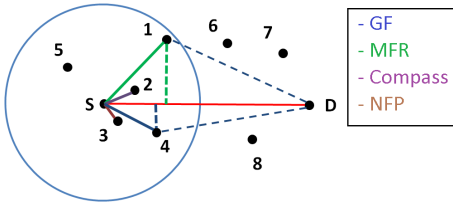
Fig. 2.   Forwarding Methods without navigation

the greatest progress towards the destination and thus Node #1 is selected. On the other hand, the "Nearest Forwarding Progress" (NFP) scheme was proposed in [33] which selected the node with the least positive progress (Node #3 from the example). The aim is to minimize transmission power so that interference and power consumption are reduced. The third approach that uses the notion of progress was made in [38] which proposes to randomly select one of the nodes that provide a positive progress towards the destination (any of the nodes #1 - #4 from Fig. 2) and simultaneously adjust transmission power. The last greedy approach, known as compass routing [52], tries to minimize the angle of the selected node and the direct line between source and destination. In our example, using this method, Node #2 would be selected because the angle $\widehat{2SD}$ is the smallest. All these approaches are based on random mobility model (such as Random Waypoint) which is not suitable for VANETs with the constraints of the roads. Moreover, the nodes are treated as static without considering their speed and heading.

B. Forwarding with Navigation

To increase the performance of routing in VANETs, protocols which employ navigation information are introduced. The knowledge of the underline road topology and the movement of the nodes can be of great importance to improve the design of a routing protocol. Using Fig. 3 as a reference for this section of the paper, we can see that the use of greedy forwarding approaches fail to select the correct forwarding node in urban environment. For example, source Node S using GF or MFR is the closest towards destination Node $D1$ but due to the building blocking the communication, it can't reach it directly. Different approach has to be followed utilizing navigation information. However, in addition to the two previous basic assumptions (use of position system and location service), a third assumption has to be made for this kind of schemes. Nodes should be aware of the road network which again is a valid assumption since most of the vehicles are equipped with navigation devices that can provide such functionality.

Two schemes, Advanced Greedy (AG) and Restricted Greedy (RG), define "anchor" points at each intersection (e.g. I1, I2 etc in Fig.3). At each intersection, a node is assigned dynamically as the co-ordinator. A node will search for a route towards the destination within the graph of interconnected junctions using a well-known algorithm, such as Dijkstra, and identify the minimum number of intersections that a packet has

to pass through. For example, the shortest path from source Node S to destination Node $D2$ is through intersections I4, I5 and I6 respectively. Then, the node will try to forward the packet towards the first intersection using one of the previous map-less greedy approaches. Once the packet has reached a node at the intersection (e.g. node #1 at intersection I4) it will then be forwarded towards the next intersection (intersection I5) using again a greedy method. Protocols that use this kind of approach are CAR [37], GPCR [30] and GyTAR [21]. One optimization on this approach is made in GPSRJ+ [28] where the forwarding node can predict the road that the packet will follow and thus skip the co-ordination node at the intersection. Therefore, decrease the number of hops. A different approach is to enhance the beacon messages used for neighbour discovery with additional information such as speed, heading etc. Using this additional information, a node can make smarter decisions on the forwarding nodes (e.g. forward towards nodes on the same direction because those links potentially last longer and therefore are more reliable). Protocols that use this scheme include VADD [59], A-STAR [48], AGF-GPSR [36] and Optimized GPSR [39]. Similar to the latter, using the information about velocity, a node can predict the current position of another node from its latest known position and the time difference between present time and the time it received the last beacon. This method is used in VADD [59], MP2R [56], and MAGF [5]. Using prediction, a node can make more accurate decisions regarding forwarding, thus there is an increase in the performance of the routing protocol. GPSR-L [44] introduced the concept of lifetime of a communication link in the routing. Using the information about the speed and position of a node, it can predict the time it will remain in the communication range (assuming a uniform circle communication) and thus select the forwarding node accordingly. Finally, more advanced schemes use information about the vehicle traffic and the road network, such as the maximum speed of a road (VADD [59]) and the traffic density (GyTAR [21]), when calculate the next hop. The disadvantage of "anchor" approaches is that they are not very dynamic. If the destination changes its position, the optimal sequence of intersections should be re-calculated. Also, the overhead is increased since this sequence of intersections is included in each packet. Additionally, signalling overhead is injected in the network close to intersections for the identification of the intersection co-ordinator. On the other hand though, prediction is a mechanism that can potentially increase the performance of the protocol that employs it. The use of traffic information, although it increases the probability of finding a better forwarding node, increases the overhead introduced by the protocol which is undesirable in large ad-hoc networks such as VANETs. Finally, the use of link lifetime is something useful especially for providing higher QoS. However, the method proposed in GPSR-L with the assumption of uniform radio range is not applicable in VANETs due to the characteristics of the channel.
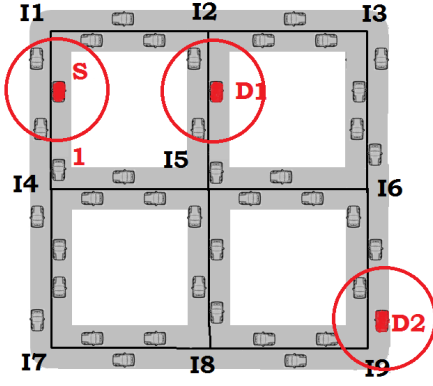
Fig. 3. Forwarding Mechanisms for VANETs

C. Recovery Strategies

In the previous sections we presented various "greedy" forwarding methods used in routing protocols for VANETs. As we mentioned, one of the drawbacks of position-based routing is the *local-maximum* problem. A node falls in the state of *local maximum* when it is the closest one towards the destination without being inside the communication range of the destination as shown in Figure 4. In this example, the Greedy Forwarding policy is employed. The same problem can be observed with any other forwarding policy. The incision between the circle with radius the communication range of a node and the circle with radius the distance between source and destination (grey area) does not include any other node. However, there might be other possible routes (S-1-6-7-D and S-5-9-8-D) to reach the destination, which can be found by employing a recovery strategy. The improvements that are proposed using navigation and other information aim at minimizing the probability that a node will fall into the *local maximum* state. However, this is not always possible. Two fundamental solutions exist for this problem. The first and simplest approach used when a node falls in the local maximum state, is to drop the packet. Although such an approach may seem easy, it produces high packet loss rate and therefore is not suggested. However, if the packet is time critical and does not tolerate any delays, then this is the only option. The second, is to find another feasible path that may not comply to the initial greedy method. One such solution is the Enhanced Greedy forwarding used in CGGC protocol [32]. This proposes to delay the packet for a short period (random) and then try to resend it hoping that the node has left the local maximum state. If again there is no node to forward it, the packet is dropped. Further improving this approach by actively selecting when a packet will be resend is known as *carry-n-forward* or "mule" [11]. Each node has a buffer with either limited time or limited size that stores packets which could not be forwarded with greedy methods and have fallen into *local maximum* state. Packets will then be forwarded using vehicle's speed until another forwarding node can be found.

If the packets time out or there is not enough space in the buffer, they are dropped. Various protocols use this scheme, e.g. SAR [45], MoVe [27], VADD [59], and GyTAR [20]. A colouring mechanism is used instead of the *carry-n-forward* in some MANET routing protocols [6], [4]. A node that is in the *local maximum* state changes its "colour" and packets are forwarded towards "greener" nodes (nodes that are not in *local maximum*). As we discussed previously, schemes such as AG and RG define anchor points that a packet has to be forwarded through. If a node falls in the local maximum state, one solution is to try and re-route the packet through different intersections, like in the colouring mechanism, if there is another path with the same number of intersections. Improving this approach by deleting the road segment that *local maximum* appeared and then re-routing was proposed by A-STAR [48] and improved GPSR [54]. Using the example in Figure 3, assume the source Node S had selected the route through I4, I5 and I6 to forward its packets towards destination Node $D2$, and was faced with *local maximum* between intersections I5 and I6. Adopting the latter method, the road segment between I5 and I6 would be deleted from the network and thus the new paths now include 4 intersections instead of 3 which was the shortest. Similar approach is proposed in DFS (Depth-First-Search) [53] where the node memorizes and deletes the paths that are defective. In GPCR [31] there are two kinds of nodes, coordinators nodes located at junctions and simple nodes between two junctions. If a coordinator node is faced with the *local maximum* problem, then the right hand rule is used to select on which road segment to forward the packet assuming that the topology of the city is a planar graph. It is not mentioned if there is a recovery strategy for simple nodes. Finally, a more complex recovery strategy known as perimeter routing was proposed in GPSR [23]. It suggests that a node can generate the planar graph of the network and from that using the right hand rule can find a path towards the destination. Using the reference network in Figure 4, node S would have to forward the packet to node #1 even though that is not the closest one to the destination. Such approach is not useful in VANETs due to the mobility and environment constraints. However, caching packets, that do not have strict QoS requirement in end-to-end delay, is a logical in VANETs approach since there is adequate memory capacity and the mobility is relatively high.

IV. CROSS-LAYERING DESIGNS

The development of communications was based on the seven layered OSI model where layers were able to interact only with the adjacent ones. The introduction of internet has reformed this 7-layered approach to a compact 5-layered that is mostly known today. Each of these layers has a distinct functionality. With respect to wireless ad-hoc networks these functionalities can be described as follows. Adopting a bottom up approach, the physical layer (PHY) is responsible to make the actual data transmission, adapting to the changes of the wireless link and perform all the signal processing mechanisms. Above that, there is the data link layer with
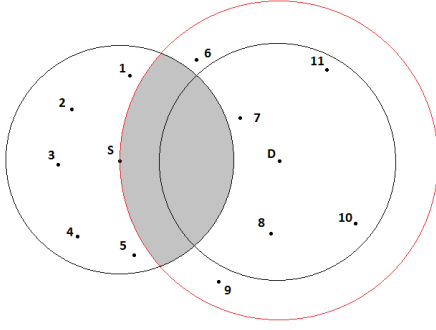
Fig. 4. Local Maximum Example

the Media Access Control (MAC) sub-layer. They are responsible to minimize collisions on the shared channel, provide fairness among the users and reliability by detecting errors from the PHY. In the middle lays the Network layer (NET) which maintains seamless connectivity among the nodes using a routing protocol. It is also in charge of distributing the information about the communication link used to maintain this connectivity. On top of NET, is the Transport layer which provides transparent transfer of data between end users with reliability, or not, depending on the used protocol. The most commonly used protocols are TCP (reliable) and UDP (unreliable). At the top of the 5-layered model stands the Application layer (APP) which runs the user application. We can see distinct functionalities for each one of these layers. However, in order to support adaptability to the challenging vehicular environment and perform certain performance optimizations, a new approach of interconnected layers was proposed, known as cross-layering.

There are different types and categories of cross-layering depending on the number of participating layers and the direction of the additional information flow. For instance, some cross-layer interactions commonly used are: the channel state information (CSI) in order to adapt throughput, the number of MAC layer retransmissions as a metric for the quality of the link, the quality of the incoming packet information as a metric for the routing algorithm, MAC layer error control as means of providing QoS at TCP or the priority of the message from Application layer on different schemes for better QoS. As it can be understood, the possibilities of optimizations and interactions are limitless and usually depend on the requirements set for each specific system. Our interest is mainly optimizations of the network layer, and more specifically use of cross-layer information from various layers to adapt routing decisions optimizing a vehicular system performance. To this end, we present various proposals for cross-layering that could be used in a vehicular ad-hoc network. A more extensive survey on cross-layer designs for VANETs can be obtained in [19].

A. Network with lower layers

First of all, we start with cross-layer designs of NET and lower layers (MAC and PHY). The main objective of these approaches is to use channel quality information from PHY and number of retransmissions from MAC as means of link quality prediction based on which the routing protocol will perform the path selection. Protocols presented in section III do not take into account these characteristics. They make use of simple metrics such as hop count, distance or enhancements of these, including navigation info. Using information about the received signal strength and arrival time of packets at the PHY, authors in [50] calculated the Link Residual Time (LRT) metric. This is an indicator of the remaining time that the specific link can be used for transmission. LRT is "exposed" to upper layers, such as routing. However, calculating LRT is not trivial. It requires removal of the noise from the data, estimation of the model parameters and finally renewing LRT. The advantage of this approach is that is generic; LRT can be used by any other upper layer. On the other hand, SBRS-OLSR [49] is restricted to OLSR. Here, SNR information from PHY is used by the OLSR routing protocol in order to select the best MultiPoint Relay (MPR) nodes; the one with the highest SNR. These nodes are responsible for the topology broadcasting contrary to the initial OLSR where all nodes were broadcasting topology information. MOPR [34] on the other hand uses movement information available at the MAC layer to predict the future positions of the relay nodes and calculate the "link stability" based on which the forwarding selection will be performed. Since this is MAC layer information, the upper network layer could be either a topological protocol or a geographical. It may seem similar to GPSR-L [44] but in MOPR the position information is available at MAC whereas in GPSR-L it is directly available to NET thus it is not counted as cross-layer protocol. Another protocol that uses MAC information is R-AOMDV [8]. It combines transmission count available at MAC and hop count available at NET to calculate its routing metric thus providing QoS based on the complete path and not only per link. A triple constrained routing protocol to provide better QoS in VANETs is DeReHQ (Delay-Reliability-Hop) [40]. It is based on AODV but also considers the end-to-end Delay, link Reliability, and Hop count giving different priorities in these metrics. The previous routing protocols were based mainly on topological approaches, using hop count as their main route metric enhanced with some cross-layer information. However, as we mentioned in section II, geographic routing performs better in VANETs. PROMPT [18] is a geographic routing protocol which has a bi-directional cross-layer design. It is developed for Vehicle-to-Infrastructure applications and provides (a) delay-aware routing through traffic statistics collected in MAC and (b) robust relay selection at MAC layer supported by mobility information from NET. Another geographic protocol is proposed in [2]. It can predict the life-time of the communication link using stability metrics (positions, speed, direction) throughout the path thus selecting the more stable route to destination. Finally, a cross-layer design for heterogeneous MANETs is proposed in [58] where nodes with different communication capabilities impose problems in routing due to link asymmetries. The solution is given by the collaboration of MAC and NET using hierarchical

location service based on node density for the routing protocol and a multi-channel MAC to cope with link asymmetries. Such an approach could be useful for VANETs since there exist different types of nodes (vehicles, roadside units etc) which potentially have different capabilities.

B. Network with upper layers

The second category that we present includes cross-layer protocols which use higher layer information to compute the path at the network layer. The objectives of these approaches are to provide different level of service depending on the priority of the packet; e.g. safety applications require faster dissemination than infotainment. A novel cross-layer protocol for VANETs is the VTP (Vehicular Transport Protocol) [47]. It combines the transport layer with network, using position-based routing to disseminate packets. Feedback information regarding bandwidth availability is passed from NET to transport layer using piggybacked ACK packets in order to provide congestion control. Another cross-layer design is proposed in [7] where the authors try to optimize TCP and GPSR [23] for vehicle mobility with adaptive interval of "HELLO" messages depending vehicle speed.

C. Network with multiple layers

Finally, there are approaches that combine more than two layers. An example of these is presented in [60], where MAC, NET and Transport layer are jointly used for optimization. With their joint algorithm they adapt persistence probability at MAC layer using flow rate information. Then, using this information at transport layer they adjust the source rate for rate control. At the end, routing is performed over the chosen link using the rate calculated before.

To summarize, the use of cross layer designs is the step forward. It is clear that the challenges imposed by the vehicular environment can not be solely faced by single-layered approaches. However, the amount of cross-layer information is an issue that should concern the researchers. The designs should be modular like in the OSI model but provide generic interfaces to other layers so that new protocols can be imported without a complete reconstruction of the protocol stack.

V. LOCATION SERVICES

In section II we mentioned the two fundamental assumptions that have to be made in geographical routing protocols; the use of position system and location services. In this section, we aim to answer the question how to identify the position of the destination? To this end, we give a brief overview of location services (LS) used from geographic routing protocols. A high level taxonomy of them is based on the percentage of nodes that host these services. If all of them host it, usually flooding based approaches, or if a smaller subset of them host it, rendezvous based [10].

A. Flooding Based Location Services

Similarly to topological routing, flooding based LS is divided into proactive and reactive based on how the node updates its location information. In proactive LS, each node periodically broadcasts its position to other nodes which update local database with the most recent position information. An optimization for high mobility that takes into account the "distance effect" is proposed with DREAM (Distance Routing Effect Algorithm for Mobility) [3], where the broadcast interval is adaptively changed according to mobility. On the other hand, reactive LS, such as LAR [25], employ an on-demand policy. If they can not find recent location information, they flood a query. Similar reactive LS is proposed by ETSI [12]. A recent location service specifically designed for VANETs is MALM [35]. It utilizes vehicles' mobility to disseminate the location information. Exploiting the Kalman filter it predicts the current or future position of another vehicle from the historical location information of other nodes.

The overhead introduced by these services is something that was studied in [26] and was found the same for both proactive and reactive LS assuming that node's mobility is independent and they adjust their transmission range to maintain connectivity. However, such assumptions are not valid in VANETs since the mobility of the nodes is not independent. Moreover, most of these LS are designed for MANETs. Having seen the differences they have with VANETs, new LS should be designed optimized for the mobility in vehicular networks.

B. Rendezvous Based Location Services

In rendezvous based LS, not all nodes host the service, but there are predefined nodes that act as location server and the rest nodes are associated with one of them. The location updates are not broadcasted to every one, but their are directed to these server nodes. Also, any query regarding the position of another node is again targeted on these nodes. The classification of rendezvous based LS is done according to the association approach. There are two types, the quorum-based and the hashing-based. In quorum-based approaches, the set of nodes is divided into two subsets (quorums), namely the update quorum and the query quorum [14]. The intersection of these two sets is designed not to be void in order to satisfy any query from one set using the information from the other. The second type of rendezvous LS uses a specific function (hash function) that according to the node id or the location space identifies the server nodes. This can be further divided into hierarchical or flat LS whether there is a logical hierarchy among the nodes or not. Some characteristic hashing-based LS are: (a) GLS (Grid Location Service) [29], Homezone [51] and HLS (Hierarchical Location Service) [24]. In GLS the area of nodes is divided into hierarchical grid squares. Each higher order grid contains four grids of the lower order. In Homezone the position of a node is stored in a virtual homezone for which the position is derived from the hash function. Nodes moving in the homezone area of another node have to maintain the location of that node. The size of the homezone can be adaptively changed according to the density of the nodes. A novel LS for VANETs is RLSMP (Region-based Location Service Management Protocol) [46]. It utilizes mobility patterns to increase scalability and employs message

aggregation for reduced overhead in querying. Finally, MG-LSM (Mobile Group Location Service Management) [57] also uses mobility information to group nodes travelling in the same direction and assigning one of them as a server. The result is longer lasting association of a node with a server therefore less overhead.

VI. SUMMARY

In this paper we have studied the routing protocols that have over the years been proposed for VANETs. The challenges opposed by the characteristics of VANETs favour the use of geographical routing against topological, hierarchical or flooding. However, using position information for the forwarding is not enough for reliable and efficient packet dissemination. It has to be enhanced with navigation information since the nodes are vehicles and their mobility is constraint by the road network. Geographical routing comes with a limitation; the *local maximum* problem. An appropriate recovery strategy should be employed to cope with this and since the nodes move with relative high velocities rapidly changing the network topology, the *carry-n-forward* mechanism is the most suitable. In Intelligent Transportation Systems, there are different applications that require reliable wireless communications with certain QoS constraints. Simple geographical routing fails to meet these requirements, therefore cross-layer designs have been proposed. One important approach of cross-layering is the use of channel characteristics to evaluate link quality. This imposes a challenge in order to model accurately the wireless channel in urban scenarios due to buildings and interference. Finally, since geographical routing requires a location service, the design of a suitable for VANETs is vital. The key challenges faced in location services is the signalling overhead and the accuracy of their reply. Several designs have been proposed that utilize navigation information and other facilities to reduce the overhead and predict the current position of the destination. Table I presents a summary of all protocols studied in this report, showing their type (topological, geographical etc), the metric that is employed by the protocol for the path selection, whether or not a navigation system is used, the recovery mechanism employed to cope with the *local maximum* problem and finally if it is a cross layer design, which layers are coupled.

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TABLE I: Summary of routing protocols for VANETs

Routing Protocol	Type	Routing Metric	Navigation	Recovery Method	Cross-Layer
OLSR [9], DSDV [43]	topological (proactive)	hop count	✗	✗	✗
AODV [42], DSR [22]	topological (reactive)	hop count	✗	✗	✗
TORA [41], ZPR [15]	topological (hybrid)	hop count	✗	✗	✗
HRS [17]	topological (hierarchical)	hop count	✗	✗	✗
GPSR [23]	geographical	distance (euclidean)	✗	perimeter routing	✗
[13]	geographical	distance (euclidean)	✗	✗	✗
MFR [55]	geographical	distance (most forward radius)	✗	✗	✗
NFP [33]	geographical	distance (nearest forwarding progress)	✗	✗	✗
[38]	geographical	distance (random positive progress)	✗	✗	✗
Compass [52]	geographical	angle	✗	✗	✗
CAR [37], GPSRJ+ [28]	geographical	distance plus number of intersections	✓	✗	✗
GPCR [30]	geographical	distance plus number of intersections	✓	right hand rule	✗
GyTAR [21]	geographical	distance plus traffic density and intersections	✓	Carry-n-forward	✗
VADD [59]	geographical	distance plus prediction, road speed limit	✓	Carry-n-forward	✗
A-STAR [48]	geographical	distance plus prediction	✓	Re-route using different anchor points	✗
AGF-GPSR [36]	geographical	distance plus number of intersections	✓	Re-route using different anchor points	
Optimized GPSR [39]	geographical	distance plus number of intersections	✓	✗	✗
MP2R [56], MAGF [5]	geographical	distance plus prediction	✓	✗	✗
GPSR-L [44]	geographical	distance plus lifetime	✓	perimeter routing	✗
CGGC [32]	geographical	distance (euclidean)	✗	random delay on packet retransmission	✗

TABLE I – Continued

Routing Protocol	Type	Routing Metric	Navigation	Recovery Method	Cross-Layer
MoVe [27], SAR [45] [6], [4]	geographical	distance (euclidean)	✗	Carry-n-forward	✗
	geographical	distance plus colour	✗	Colouring	✗
Improved GPSR [54]	geographical	distance (euclidean)	✗	Re-route using different anchor points	✗
LTR [50]	geographical	distance plus LTR	✗	✗	NET + PHY
SBRS-OLSR [49]	topological (proactive)	hop count	✗	✗	NET + PHY
MOPR [34]	topological (reactive)	hop count plus link stability	✗	✗	NET + MAC
R-AOMDV [8]	topological (reactive)	hop count plus Tx count	✗	✗	NET + MAC
DeReHQ [40]	topological (reactive)	prioritized delay, reliability and hop count	✗	✗	NET + MAC
PROMPT [18]	geographical	distance plus MAC statistics	✗	✗	NET + MAC
[2]	geographical	distance plus mobility metrics	✗	✗	NET + MAC
[58]	geographical	distance (euclidean)	✗	✗	NET + MAC
VTP [47]	geographical	distance plus bandwidth availability	✗	✗	NET + Transport
[7]	geographical	distance (euclidean)	✗	✗	NET + Transport
[60]	geographical	distance plus rate and MAC info		✗	NET + MAC + Transport