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An Overview of Routing protocols in Vehicular Ad Hoc Networks (VANETs)

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ABSTRACT

In the last years many routing protocols have been proposed for VANET by taking into account its specific characteristics, including the frequent change of the topology, the high vehicles' speed and non random movement of vehicles. There are different classification types that have been used to represent routing protocols in VANET. This classification differs from one author to another and it not takes into account several factors. In this paper, we present an overview of the existing routing protocols in VANETs taking into account a new classification. We start by the challenges of routing in VANET, followed by a detailed discussion of single-layer routing with more focus on geographic routing protocols. The Cross-layer routing protocols are discussed afterwards. Finally, we underline some open issues in developing efficient routing protocols in VANETs.

Key words: Routing in VANET, Single-layer routing, Cross-layer routing, Position-based routing, Non-DTVANETs, DTVANET

1. INTRODUCTION

VANETs are a one of the key components of the ITS system, which provide wireless communication between vehicles. By integrating wireless communication devices into vehicles, the vehicle can communicate with other vehicles directly by forming a vehicle-to-vehicle (V2V) communication or communicate with fixed equipment near the road forming a vehicle-to-infrastructure communication (V2I) [1], [2], [3], [4], [64]. VANET technology provides a variety of driver and passenger applications and services, and assists the relevant authorities to better control road traffic [5], [6].

In vehicular networks, vehicles can exchange information in real time, travelers can use this information to do their business (check their email) and drivers can be informed about traffic conditions and other travel-related information [3], [5]. The behavior and characteristics inherent in VANETs raise important challenges that should be taken into account in effectively deploying these networks. The most difficult problem is potentially high mobility, frequent changes in network topology and variation in vehicle density from time to time throughout the day. Indeed, the topology of the network can vary when the vehicles change their speeds and/or their lanes on the road. These changes depend on drivers and road situations and are not normally planned in advance.

Because of the specific characteristics of vehicular environment, the VANETs successful deployment consists of a number of important components, a key one of which is to establish adaptive and efficient routing routes between source and destination vehicles in urban and highway scenarios. There have been several proposals in the literature to deal with the challenges of routing protocols in VANETs.

Many studies show that the topology-based routing protocols have difficulties in dealing with the forte mobility related to the vehicular ad hoc networks in urban as well as in highway traffic scenarios. Geographic routing protocols were shown to be the most adequate to the VANET due to their robustness in dealing with the dynamic environment changes and the high mobility of the vehicles. Therefore, geographic routing appears to be a more promising approach as compared to traditional topology based routing, where the use of position information gives an additional advantage for reaching superior performance. Cross-layer routing exploits the dependency between protocol layers to exchange information among different layers to reach improvements in network performance by including parameters at the PHY, MAC and NET layers.

Even if this literature on routing issues are abundant and rich, there are still several problems to be solved, such as the frequent failures of the route caused by the high mobility of vehicles, the growth of the network overload caused by control messages and the increase of the data packet delivery time. However, in designing routing protocol, various routing approaches should be taken into consideration. The routing approach must cope well with the challenging characteristics and dynamic network topology of the vehicular environment. In general, the design of reliable and efficient routing protocol in VANETs still remains a key and widely open research issue.

The rest of paper is organized as follows. Section 2 presents routing challenges in VANETs. Section 3 presents routing protocols classification taking into account single-layer and cross-layer routing. Section 4 presents open research issues. Finally, we give a conclusion in Section 5.

2. ROUTING CHALLENGES IN VANETS

Routing still remains an important research issue in VANETs [7]. Routing protocols in VANET aim to make use of intermediate vehicles as relays in order to deliver data packets to the intended destination vehicle. VANETs are different from other ad-hoc networks such as MANETs, and have their own constraints that pose important challenge for the routing. However, they also have certain features, such as constrained mobility and access to positional information that offer a support while routing [8]. Hence, It is required to design a routing protocol that takes into account the challenges and unique characteristics of VANETs. Some of the technical challenges and designs are as follows:

Scalability: One of the principal characteristics of vehicular networks is scalability [9]. Therefore, the performance of the routing protocol must have minimum effect on varying the density of vehicles in the network [10]. This is feasible if the protocol is capable of performing localized operations where routing decisions taken by a vehicle are only based on information obtainable in its neighborhood. This eliminates the necessity for the vehicle to know the topology of the entire network, thus the decrease of the control overhead [8].

Discovery of neighborhood: One of the routing protocol basic parts is the discovery of neighborhood, that can be done either during route establishment or by sending one hop beacons messages. The use of short periodic interval for beaconing may result an in augmentation of control overhead, while big periodic interval for beaconing involves old neighborhood information. Therefore, a correct selection of beacon interval period is required for offering good trade-off between control overhead and updated information. Some protocols use adaptive beaconing based on certain characteristics of the vehicular environment such as mobility and density of vehicles [11]. Another recent and attractive approach is the approach without beaconing that requires reactive discovery of neighbors during forwarding of data packets [8] [12] [13].

Uneven density of vehicles: The vehicular communication environment also encounters the problem of irregular vehicles density, where some regions have sparse traffic conditions while others are dense because traffic density fluctuates significantly from downtown to suburbs and from day to night. Besides, spatial distribution of vehicles over road segments can be bumpy, since vehicles tend to pile up at intersections, leading to sporadic connectivity. The routing protocol requires adapting to the varying traffic density conditions. In case the region is highly congested, the protocol must be capable to minimize the congestion by finding a good path. In sparse traffic conditions, a vehicle can carry the message until a suitable forwarding vehicle appears. Furthermore, it would be more suitable to have an adaptive scheme [14] that changes its operation mode based on the traffic conditions [8].

Positional information use: Vehicles have access to positional information through navigational devices as GPS. This information offers important advantages to routing solutions [15]. It is very motivated for routing protocols to take into consideration the positional information while selecting path and neighbors as these will further help in improving the routing performance [8].

Future positions prediction: The access to positional information and the constrained mobility pattern permit vehicles to predict their future positions. This information allows the protocol to make efficient routing decisions. The more the mobility model and the prediction are close to the reality, the more the performance evaluation of the routing protocol is valid [17]. However, we must be careful at the prediction process because imprecise information may lead to selection of a non optimal path [8] [16].

3. ROUTING PROTOCOLS CLASSIFICATION

There are different classification types that have been used to represent routing protocols in VANET. Firstly, we will begin by authors in [8] that classified the routing protocols in two kinds as following:

3.1 Single-layer routing

In this type, the classification of routing protocols depends on a number of factors. Authors in [7] [18] classified the routing protocols into topology-based, position-based, cluster-based, broadcast-based and geocast-based routing. The classification in [9] was based on the type of communications (V2V and V2I). VANET routing protocols were also classified based on the type of information used in forwarding [19]. Our classification single-layer is based on [8], [19] and [20], and splits into two major families of protocols: Topology based routing and Position-based routing (Geographic routing).

3.1.1 Topology-based routing protocols

Topology-based routing protocols use the information about the links that exist in the network to identify the best path to forward data packets. The route is established through control packets prior to data transmission. They are further classified into reactive, proactive and hybrid protocols [8], [21], [63].

Reactive protocols, also known as on-demand routing, find the route to a destination when a vehicle needs to start a session with that destination and maintains solely routing paths that are currently in use. Reactive protocols consume less bandwidth, have low memory requirements, and respond well to link failures [8]. However, they have two main problems that make them inadequate for VANETs [21]. First, due to the reactive nature of the protocol, the establishment of communication requires an important delay [18]. Second, the packet delivery ratio is low when the source and destination vehicles are far away as the probability of a broken route increases due to the high mobility of vehicles. Ad-hoc On-demand Distance Vector (AODV) [22] and Dynamic Source Routing (DSR) [23] are examples of reactive routing protocols.

Proactive protocols establish the route based on shortest path algorithm, and then maintain the routes by storing routing information about vehicles in tables. The routing tables are shared between vehicles more than just the one-hop neighbors and are updated when a change in the network topology happens. Whereas, this type of protocols reaches low latency, it has an important overhead due to the periodical information transfer and the propagation of routing messages to destination vehicle that might likely become obsolete information because of the highly mobility of vehicles. Besides, these protocols do not respond well to link failures, and then they are not suitable for VANETs [9], [18]. Examples of such protocols are Optimised Link-State Routing (OLSR) [24] and Destination-Sequenced Distance Vector (DSDV) [25]}.

Hybrid ad-hoc routing uses both proactive and reactive features to minimize routing overhead and delay during the route request discovery. Hybrid protocols do not work very well in high mobility of vehicles and frequent changes of the network topology [9], [18].

The performance evaluation in [26] shows neither OLSR nor AODV are able to provide acceptable packet delivery ratio in VANET scenarios. Authors in [27] show also the performance of AODV is poor in establishing long routes. In general, topology-based routing protocols are not suitable in VANETs because they do not perform well in dynamic network due to their low communication throughput [7]; also they become invalid even prior to sending data packets [28], and they have important overhead which is caused during route discovery process [29].

3.2 Position-based routing protocols

Position-based protocols or geographic routing protocols use the position of the vehicles to take routing decisions and thus selecting the best route to forward the data packets. One of the first position-based routing protocols is based on the concept of progress to destination. An enhanced solution has been proposed in which the selection is based on the geographical distance to the destination vehicle. Instead of using the progress towards the destination as a metric, some authors propose a direction-based approach which uses the angular deviation from the line between the forwarder and the destination vehicles.

In the geographic routing protocols, it is assumed that each vehicle has location information obtainable by the positioning system like the GPS device. For these protocols, the vehicle requires to know the position of the destination vehicle that is obtained by using a location service, such as the Grid Location Service (GLS) [30], the Reactive Location Service (RLS) [31] or the Hierarchical Location Service (HLS) [32].

Authors in [8] classified geographic routing protocols on the basis of two perspectives (routing mechanism and the used geographic metric).

We can classify geographic routing protocols based on three perspectives: routing functionality (routing strategies), routing mechanism, the used geographic metric and the intermittent connectivity.

3.2.1 Classification based on routing functionality

Authors in [19] divided routing functionalities in three different aspects which are path selection, forwarding and recovery.

Path selection: Two of the most popularly used path selection strategies are as follows:

One popularly used path selection strategy is the one which is based on the well known Dijkstra algorithm, in which a path between source and destination vehicles is computed at the source vehicle, with the junctions and intersections as the graph edges. This strategy named full path using Dijkstra [19]. When using this strategy, each packet bears the location of all junctions to be traversed. Different metrics can be used to compute the cost of the paths. Some routing solutions consider that the cost of each road is the distance [33], whilst others use more attributes to weight the cost. For example, authors in [34] use the information of the number of bus lines to weight the paths.

The strategy of full path using Dijkstra poses two principal problems which are the overhead and the reduced availability. It has a significant overhead as each packet requires bearing information through the entire path. It also has reduced availability due to frequent disconnection problems that might occur, because the route selection takes into consideration neither the number of retransmitting vehicles nor the vehicles mobility. Thus, one may select a route which does not have sufficient vehicles to guarantee the connectivity. Even if the number of vehicles was taken into account, by the time the packet arrives at a given road segment, all vehicles could be long gone [19].

Another used approach is to select, at each junction, which road to follow next [35]. This approach is named as next junction selection. So, each time a packet arrives at a junction the vehicle which bears it selects which of the surrounding roads is the best to follow and selects a vehicle which uses that road. This can be done using different metrics; the most frequently used is a combination between the progress toward the destination and the vehicle density of that road. Each of the metrics can have a different weight. The weight of each metric can be set depending on what is more important [35].

This solution does not increase the overhead as much as the full path using Dijkstra because only one position is involved beside the position of the destination. Moreover, as route selection is carried out hop-by-hop, at each junction there is a poor likelihood of disconnection since routing decisions are transferred and when they are taken, the vehicle has an updated view of the neighborhood conditions and thus a significant availability is anticipated. When the used metric is the density the availability is even higher since a road with few vehicles would not be selected [19].

Forwarding strategies: The greedy forwarding is an effective forwarding solution and it is used by authors in [36]. In this technique, the sending or forwarding vehicle sends the packet to the neighbor that is closer to the destination. Because each vehicle knows the positions of its neighbors that are carried by hello messages; also the position of the destination vehicle is in the packet header. In malignity of its simplicity, greedy forwarding can lead to an inappropriate selection of vehicles, as being the closest vehicle to destination does not necessarily mean it achieves the destination vehicle or that it is the best route to it.

When any type of route is used, we can use greedy along the path that is the greedy approach but considering only the vehicles that are on the selected road to next junction [35]. While improving the basic greedy forwarding, it still may cause an inappropriate selection of the forwarding vehicle, because of an underestimation of the physical conditions as propagation and vehicles mobility.

To overcome previous problems, the restricted greedy approach is used. This approach based on the existence of a priority vehicle in the centre of the junction, such as if such vehicle is a neighbor of the sending vehicle, the latter would each time send data to that priority vehicle. If vehicles move very slow or do not move, the vehicle in the centre of a junction remains the same and receives all the arriving traffic. Therefore, it may make a communication bottleneck [35], [37].

Recovery-mode strategies: Greedy forwarding strategies can encounter a situation in which the sending vehicle is closer to the destination vehicle than all of its neighbor’s vehicles, and the destination vehicle is not accessible by one hop. This situation called local maximum problem or local optimum problem. However, this does not mean that there are not enough vehicles to reach to the destination. When a local maximum problem occurs, a recovery strategy is used. Some of the most pertinent recovery strategies are as following:

The right hand rule is one the most of the recovery strategies widely used to traverse graphs. In which if vehicle m receives the packet from edge E1; it sends the packet through its next edge counterclockwise about m. The routing scheme switches back to forwarding mode once the forwarding vehicle is closer to the destination than the vehicle that triggers the recovery strategy [36]. As in VANETs the network vehicles are moving with a high speed, this can lead to loops in the right-hand rule technique.

The carry-and-forward is another technique that is used to face the local maximum problem [30]. In which, when the local maximum problem occurs the vehicle carries the packet until an admissible neighbor arises. This technique conducts to bigger delays.

3.2.2 Classification based on routing mechanism

Routing mechanism can be split depending upon whether or not a routing protocol uses beacon messages.

Beacon-based: in this mechanism, each vehicle periodically sends a beacon message for exchanging information among neighbors. This mechanism is known as sender-based, because a sender or forwarder previously knows its immediate neighbors, and hence it selects the best next neighbor vehicle to forward the packet. Among routing protocols of this kind are [16], [34], [36], [38], [39], [40], [41], [42].

Beaconless-based: Also called receiver-based, since receiving vehicle decides whether or not to take part in the routing process. Routing protocols in this type do not depend on beacon messages exchange. Among of these routing protocols, we cite [12], [13], [43].

3.2.3 Classification based on geographic metric

Routing protocols use a geographic metric that may be static positional information such as position coordinates or information related to vehicles mobility such as velocity, direction etc. On these bases, we classify the routing protocols in two types [8]:

Location-based: This sort of routing protocols obtains static positional information for taking routing decisions, where every vehicle knows the position of its own, its neighboring vehicles and in some cases the position of the destination. The location information is obtainable through preloaded cards or a navigational system. In case of inaccessibility of navigational system signal or cards, diverse localization services are also used to estimate the location of the vehicles.

Mobility-based: Routing based only on static positional information of vehicles cannot be effective because of high mobility of vehicles in VANET. Routing protocols in this kind take into account mobility related information such as speed, while making routing decisions to promote and facilitate the development of robust and stable data forwarding under high mobility conditions. Extracting this kind of information requires the defining of vehicular mobility model that provides a precise and realistic description of the motion of vehicles [8].

3.2.4 Classification based on the intermittent connectivity

Authors in [7] categorize geographic routing protocols on the basis of the application where they are most suitable. They categorized these protocols on three types: Non-DTVANETs, DTVANETs, Hybrid.

A. Non-Delay Tolerant Vehicular Ad hoc NETworks (Non-DTVANETs)

The Non-DTVANETs protocols do not take into account intermittent connectivity. They use the greedy strategy to forward the data packets. However, the greedy forwarding strategy can fail if no neighbor is closer to the destination than the current vehicle itself. In this case, we say that the packet has reached a local maximum. A recovery approach is used to deal with such a situation. We describe some routing protocols of this category as following:

GPSR: Greedy Perimeter Stateless Routing (GPSR) [36] does not calculate any path from source to destination vehicles. Each forwarding vehicle adds the destination location in the packet header and sends it to its neighbor that is closer to the destination vehicle, using the greedy forwarding strategy. When a local maximum occurs, the vehicle enters the perimeter mode, which uses the right-hand rule. GPSR returns to greedy forwarding when the vehicle having the packet is closer to the destination then when it entered recovery-mode.

Authors of GPSR use an approach to obtain a planar graph without crossing the network. However, this approach leads to an overhead of the network. Thereby, this recovery method is a lot more state-full than stateless. Moreover, planarization (in an urban environment frequently surrounded by obstacles) can lead to network disconnections and thus, can force GPSR to frequently run in the recovery mode, which deteriorates its performances [44], [45].

A-STAR: The Anchor-based Street Traffic Aware Routing (A-STAR) [46] is based on the calculation of a full path to forward data by using a different method than GSR [44]. In A-STAR, the forwarding vehicle calculates the anchor path by a dijkstra shortest path weighted by the number of bus lines that travel in each road. If a local-maximum occurs (because the forwarding strategy is greedy along the route) the vehicle uses a recovery strategy to recalculate a new anchor path to destination vehicle from the current local optimum. Compared to the GSR greedy approach and the GPSR perimeter mode, A-STAR uses a new local recovery strategy that is more suitable for a city environment and that shows a good enhancement in packet delivery.

However, to find a higher connectivity path between a source and a destination vehicle, A-STAR uses static information based on the number of bus lines by which the route is tended. This causes connectivity problems on some portions of streets. Indeed, most of the data traffic will be carried out on such routes and hence, this could enhance the data congestions chance.

MOPR: A MOvement Prediction-based Routing (MOPR) [47] chooses the route that is most stable taking into account the movement status of the intermediate vehicles with respect to the source and the destination vehicles. MOPR can approximately predict vehicles positions in the near futures. By knowing the size of the data to send, MOPR can know the delay the transmission of each data packet. Thus, the most stable route selection for data transmission will provide the route building by intermediate vehicles that are not likely to cause a breakage of the transmission in the near future and that can support the transmission for enough time. This approach should help as well in minimizing the broken links risk and decreasing data packet loss.

ROMSGP: in Receive On Most Stable Group-Path (ROMSGP) [48], vehicles are grouped into four different groups based on their velocity vectors. Information on groups is added in the route request messages. When a vehicle X receives a route request message from another vehicle Y, it compares its group ID with that of the originating vehicle. If the two vehicles belong to different groups, the link between them is considered to be unsteady. A penalty is then added to the routing metric between them, and routes are revised. If the two vehicles belong to the same group, routing metrics are not modified. Decision of the most stable link is made based on the calculation of the link expiration time (LET) of each route. The route with the longest LET is considered as the most stable link.

CRLLR: Clustering-based Reliable Low-Latency multipath Routing (CRLLR) [50] scheme uses Ant Colony Optimization (ACO) technique to efficiently compute the optimal routes among the communicating vehicles for VANETs in terms of reliability, end-to-end latency, energy consumption and throughput. Besides, it uses the link reliability as criteria for Cluster Head (CH) selection.

When the cluster head receives a route request from its source to the destination vehicles, it first checks that it has a cluster vehicle with information about all vehicles attached with its cluster. Then, it checks its own routing table if the destination vehicle does not belong to the cluster. In this situation, it sends a route request message to every gateway vehicle listed in the gateway. The requested gateway vehicle sends a route request message to the contiguous gateway vehicles. The gateway neighboring vehicles then demands the route request message to send it to its cluster head which confirms the existence of the destination vehicle in its own cluster (see Figure 1).

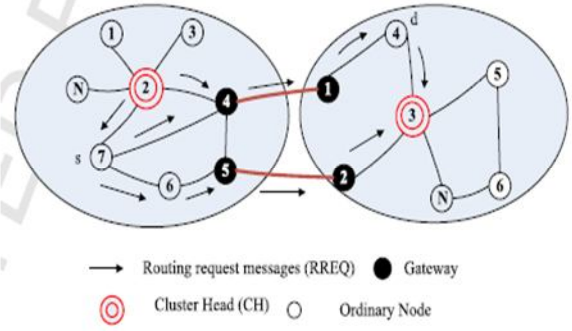

Figure 1: RREQ and RREP messages [50]

B. Delay Tolerant Vehicular Ad hoc NETworks (DTVANETs)

DTVANETs strive to bear a range of vehicular network applications typified by the delay tolerance and the asynchronous data traffic. Such applications can put up with some data losses. It uses opportunistic strategies to surmount frequent disconnections of the network. In this class, we find:

VADD: Vehicle-Assisted Data Delivery (VADD) [42] is a routing protocol for VANET that aims to decrease E2E delivery delays from a moving vehicle to a fixed destination in sparse vehicular networks by using carry-and-forward strategy. VADD is based on the use of a foreseeable vehicle mobility that is limited by the traffic pattern and the road layout. The vehicles are assumed to be equipped with preloaded digital maps which provide the street-level map and the traffic statistics such as the traffic density and the vehicle speed on roads at different times of the day. VADD has three packet modes: Intersection, Straight Way and Destination where each fashion is based on the location of the vehicle wearing the packet.

In intersection fashion, the vehicle wearing the packet can select all the outgoing directions and verifies if there is a vehicle available to help forwarding the packet via that direction. For instance in Figure 2, vehicle A has a packet to forward to a certain destination. Assuming that the optimal direction for this packet is north, there are two available vehicles for the vehicle A: B moving South and C moving north. Both choices strive to forward the packet toward the North: selecting B because B is geographically closer to the North and provides a better possibility to exploit wireless communication, or selecting C because C is moving to the packet-forwarding direction.

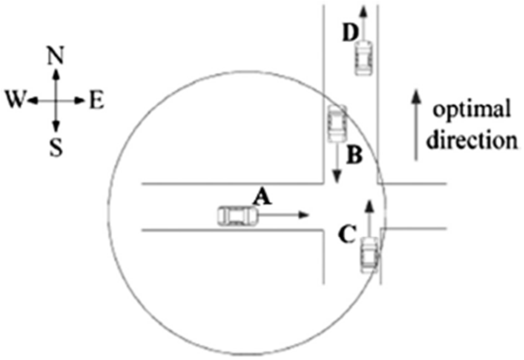

Figure 2: Select the next vehicle to forward the packet [42]

The forwarding of data in the Straight Way fashion is simpler than in the Intersection fashion as the traffic is bidirectional. The intersection ahead which is attached by the current road is directly specified as the target and then, GPSR is applied on the target location. If there is no vehicle available to forward the ahead, the current vehicle continues to carry the packet. A packet switches to the destination fashion when its distance to the destination vehicle is below a predefined threshold. The location of the destination becomes the target location, and GPSR is used to deliver the packet to the final destination. By switching between these packet fashions, the vehicle takes the best packet forwarding route.

Even if VADD is good compared with existing solutions in terms of packet delivery ratio, data packet delay and traffic overhead, it cannot permanently ensure multi-hop connectivity; especially, if unpredicted changes in the distribution of road traffic flows occur.

GeoSpray [51] is a routing protocol for vehicular delay-tolerant network that aims to optimize the resources used in the network, including: the storage, the bandwidth, and the energy, while maximizing the delivery probability and, minimizing the delay and the overhead. It is based on four principles that are: 1) Supporting an opportunistic networking paradigm and the delivery of bundles based on the store-carry-and-forward paradigm, 2) Using geographical location information provided by positioning devices to make routing decisions, 3) employing a multiple-copy routing scheme, with a strict upper bound on the number of copies per bundle, combined with a forwarding routing strategy, to improve the timely delivery of bundles across multi-hop routes and 4) clearing bundles (on intermediate vehicles) that have already been delivered to the destined vehicles.

However, GeoSpray combines the selected replication and forwards it with the explicit delivery acknowledgment. It employs the concept of spray phase and wait-mechanism [52], where a small/fixed number of packet copies are distributed to distinct vehicles in the network. However, instead of using blind replication, GeoSpray guarantees that packet copies are only spread to the network nodes which will be closer to the packet's destination.

C. Hybrid position-based routing protocols

Hybrid types incorporate the Non-DTVANETs and the DTVANETs to make use of the deficient network connectivity. When the network is dense, the greedy strategy is used for forwarding the data packets and when a disconnection occurs, the mobility of the vehicle is exploited by carrying the packet until a visible neighbor appears, or it reaches itself the destination vehicle. In this category we find:

GeoDTN-NAV [53] is a hybrid approach that combines the greedy mode, the perimeter mode, and the Delay Tolerant vehicular Network mode. The packet is first forwarded in greedy mode and when it meets a local maximum, it will be forwarded in perimeter mode. If the latter also breaks down, it switches to the Delay Tolerant vehicular Network mode. In this approach, the packets are always forwarded between junction vehicles, since junctions are the only locations where a vehicle can make significant routing decisions. If a local maximum is achieved, the recovery mode, named the perimeter forwarding, is used. It switches between modes by estimating the connectivity of the network based on the number of hops in which the packet has traveled in the perimeter mode, the neighbor's delivery quality, and the neighbor's direction with respect to the destination.

The authors of this proposal assume that every vehicle is equipped with a Virtual Navigation Interface (VNI) that allows obtaining the delivery quality of neighbors. These authors categorize vehicles based on the traffic pattern into four categories that are Deterministic Route, Deterministic Destination, Probabilistic Route/Destination, and Unknown. In the first, vehicles move strictly along preconfigured routes. These vehicles will not deviate away from their routes. Also, the vehicles moving direction can be derived from their routes. In the second, vehicles travel strictly toward a preconfigured destination. However, it is feasible that the vehicles take different routes to attain the destination vehicle. In the third, vehicles may travel based on proposed routes or destinations. They are permitted to change their unrestricted route or destination. In the forth, Vehicles could not supply information about their route, but they do not travel randomly.

GeoDTN-NAV improves the packet delivery ratio by using the delay tolerant store-carry-forward solution to qualify the impact of the intermittent connectivity. However, in a sparse network, GeoDTN-NAV is likely to fall back to the Delay Tolerant mode frequently. That leads to the increase of the latency and the decrease of the packet delivery ratio.

GGC: Guaranteed Geocast Routing (GGC) [54] is a routing protocol for VANET in order to provide guaranteed packet delivery in intermittently connected highway vehicular traffic environment. In GGR, the packet forwarding is based on four factors, namely caching of packets in intermittently connected traffic environment, neighboring vehicle speed, packet ownership transfer and heuristic function based next on hop vehicle selection. In the case where an unavailability of next hop vehicle in intermittently connected, packets could not be immediately forwarded, and thus, they will be cached. The mobility of Vehicles is used for packets delivery until an appropriate next hop vehicle is available. Neighboring vehicles are divided into two groups FAST and SLOW according to their velocity. FAST includes all the neighboring vehicles traveling at higher speed as compared to current forwarder whereas SLOW includes the remaining neighboring vehicles traveling at lower speed as compared to current forwarder. Acknowledgement is used in each successive one hop communication to transfer packet ownership that, in the end, guarantees packets delivery until destination. A next hop vehicle is selected from FAST using a heuristic based cost function. The cost function has two components which represent current and future cost of packet delivery.

3.3 Cross-Layer Routing

3.3.1 Cross-Layer Routing Parameters

Cross-layer routing exploits the dependency between protocol layers to exchange information among different layers to reach improvements in network performance [8], [55]. Integrating parameters at the PHY, MAC and NET layers while making routing decisions (see Figure 3) will allow the routing protocol to be more robust in the face of issues such as congestion and interference [8]. Characteristics of wireless channels such as signal-to-interference-plus-noise ratio (SINR) typically available at the PHY layer play a fundamental role in determining interference [56]. Parameters related to characteristics of vehicle such as buffer space [57] and retransmission count [58] are available at the MAC layer and their incorporation in the routing decision may help in minimizing congestion and packet drops. These parameters along with the characteristics of traditional

E2E route such as hop count, round-trip time at the NET layer can be used while making routing decisions in order to achieve high network performance. Accordingly, the selected route or next hop at the NET layer will have minimum effect from the above mentioned issues.

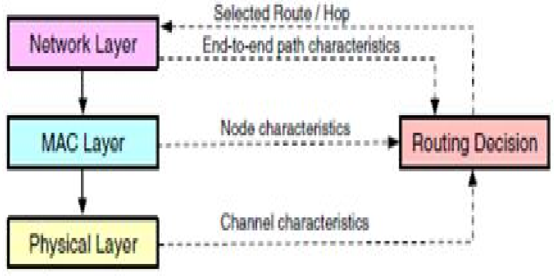

Figure 3: Routing decision based on the PHY, MAC and NET layers [8]

3.3.2 Cross-Layer Routing Protocols

The existing cross-layer routing protocols are classified based on cross-layer routing parameters, routing mechanism and used geographic metric [8]. Among these protocols, we cite:

SBRS-OLSR: Signal strength assessment Based Route Selection for OLSR (SBRS-OLSR) [59] is a cross-layer ad-hoc routing approach based on link connectivity assessment. The enhanced protocol is based on optimized link state routing and utilizes the benefit of cross-layer information exchange among the PHY, MAC and NET layers. Specifically, SBRS-OLSR makes use of multipoint relays (MPRs) concept present in OLSR [60] to maintain the routing information where only the selected MPR vehicles broadcast topological information. However, the conventional MPR selection process is modified by considering a new cross-layer routing parameter named affinity α basis for route selection. The affinity α is used to predict the lifetime of a link between the two vehicles.

LD-CROP: Location-Delay-Aware Cross-Layer Communication Protocol (LD-CROP) [61] relays packets over low delay routes to a fixed base station or access point. The packet traffic information typically available at the MAC layer is monitored and updated periodically, after which packets are routed over low delay routes. Specifically, the framework comprises three principles. Firstly, a light weight traffic information propagation system is used, where vehicles periodically exchange the succinct summary of packet traffic information based on local observation. The gathered local traffic is then used in making high level routing decisions by selecting smaller delay routes over the roadmap. Finally, the selected route is changed only when another route offers significant improvements in terms of route quality. This is done to reduce oscillations in terms of selected route. Beacons containing base station ID, sequence number, route, lifetime, and complete route quality, are constantly shared between vehicles. Each vehicle maintains route table to store route information of different routes.

CLWPR: Cross-Layer Weighted Position-based Routing (CLWPR) [62] is a unicast multi-hop routing protocol based on opportunistic forwarding. The information available at the PHY and MAC layers along with the location information is used as routing metrics for making next hop selection. HELLO beacons containing vehicle location, vehicle speed, vehicle heading, road ID, vehicle utilization, MAC frame error rate and number of cached packets, are periodically exchanged between vehicles. SINR is recorded by vehicles on beacon reception. The obtained information is used to determine the weight of the available next hops. The hop with minimum weight will be selected. The performance of CLWPR outperforms GPSR. Indeed, GPSR neither uses map information nor does it have the capability to predict the vehicle's location. On the contrary, CLWPR usage of maps information results in improved packet reception rate. Besides, the link quality consideration in terms of SINR further helps in minimizing E2E delay. Although the carry-and-forward mechanism reduces packet drops in sparse network conditions, it results in increased E2E delay.

En-AODV: the purpose of Enhanced AODV (En-AODV) [49] is to find the most suitable inter-vehicle routes that satisfy the requirements of multimedia applications. En-AODV has two major objectives that are: finding the most stable route relaying the source and destination vehicles and quickly react to the occurrence of a link failure in this route and supply an alternative link of good quality. Furthermore, En-AODV has a cross layer aspect which consists in the cooperation between the physical and network layers to select the most stable route among the available options. This is achieved by exploiting the received signal strength value at the routing level to estimate a given link lifetime.

4. OPEN RESEARCH ISSUES

Much research has been done to develop efficient routing protocols for vehicular networks, using both single-layer and cross-layer approaches. However, there are still open issues related to the routing approach that need more attention. Among open research issues, in both single-layer and cross-layer routing, are:

- The beacon overhead which increases with the vehicle density is an open issue. Thus, it should reduce the number of beacon messages in order to reach low overhead. Sharing information about the link quality is another issue. This information should be shared during beaconing.

- The transmission delay in beaconless schemes is also an open issue. Therefore, it should minimize this delay in current beaconless routing schemes.
- Making current routing schemes highly adaptive to changing network conditions of VANET is a main issue. When the network is sparse, the challenge is to maximize the chances of packet receptions; while in dense networks, the aim is to minimize the E2E delay. Thus, an efficient scheme must be able to adapt and to maintain routes when the network connectivity changes.
- Many applications impose strict quality of service requirements which may not be met by single layer network design solutions. However, any Cross-Layer design should take into account to undesirable effects which can occur due to the cross-Layer exchanges and affect the system performance. Therefore, developing a composite parameter for routing, including appropriate cross-layer parameters and addressing the issues at PHY, MAC and NET layers.

5. CONCLUSION

Routing protocols aim to make use of intermediate vehicles as relays in order to deliver data packets to the intended destination vehicle. Hence, It is required to design a routing protocol that takes into account the challenges and unique characteristics of VANETs. There are two major classification types of routing protocols that are cross-layers routing and single-layer routing. The latter is classified into two major families: Topology based routing and Position-based routing (Geographic routing). Geographic routing protocols are classified based on four perspectives that are routing functionalities (routing strategies), routing mechanism, used geographic metric and the intermittent connectivity. Characteristics of wireless channel such as signal-to-interference-plus-noise ratio (SINR) typically available at the PHY layer play a fundamental role in determining interference. Parameters related to characteristics of vehicle such as buffer space, retransmission count, are available at the MAC layer and their incorporation in the routing decision may help in minimizing congestion and packet drops. Hence, cross-layer routing exploits the dependency between protocol layers to exchange information among different layers to reach improvements in network performance by including parameters at the PHY, MAC and NET layers.

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