VANETs Networking Protocols: An Analytical Study

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***Abstract*—Vehicular Ad hoc NETworks (VANETs) are considered as a class of Mobile Ad hoc NETworks (MANETs). The VANETs are a set of vehicles that are capable of exchanging data dynamically and without needing any pre-existing and fixed network infrastructure. Each node sends and receives messages in its communication area. Thus, message routing is done through a routing protocol. Despite the fact that the VANETs are a subgroup of the MANETs, they possess exceptional network behaviors like high mobility and dynamic topology, which make the MANETs routing protocols unsuitable for the VANETs. This paper summarizes the different protocols used for routing in the VANETs that focuses on a vehicle-to-vehicle communication. Utilizing an OMNET++ simulator, the experimental results are discussed to compare the presented routing protocol categories.**

Keywords*–*VANET; Routing protocols; OMNET++.

I. Introduction

A Vehicular Ad hoc NETwork (VANET) is a communication network between vehicles equipped with computers, network devices and various types of sensors [1]. In the VANET, vehicles communicate with each other via a Vehicle-to-Vehicle (V2V) communication and with the roadside through a Vehicle-to-Infrastructure (V2I) communication. Fig. 1 shows an example of the VANET.

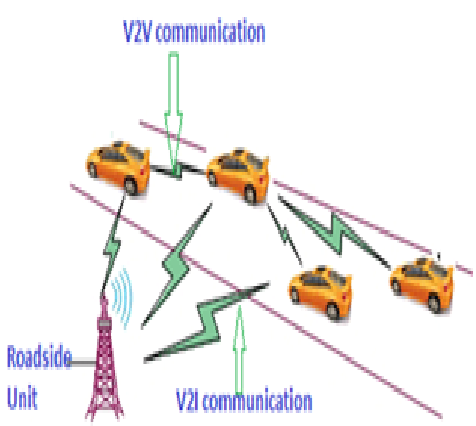

Figure 1. Example of VANET scenario.

Even though the VANET is a subclass of a Mobile Ad-hoc NETwork (MANET), it has specific network characteristics, as follows [2]:

- **High mobility**
  The VANETs are characterized by a high mobility of vehicles. Therefore, a node may join or leave the network in a very short time, which makes a very frequent change of the topology. In addition, routing problems can occur when communication links are broken suddenly due to an important velocity value, i.e., an intermittent connectivity problem.
- **Communication environment**
  The environments considered by the VANET are often unfavorable particularly in urban areas. Vehicle movements are related to road structures (intersections, traffic signs, etc.) and road base stations (infrastructure) in highways or within a metropolitan area. The constraints imposed by this type of environment, such as radio obstacles and impacts of multipath propagation, affect the quality of services as well as radio transmissions.
- **Constraint of energy**
  Unlike the MANET, where the energy constraint is an addressed challenge issue, the VANETs energy is not a critical behavior because the components of the VANET have no limit in terms of energy and may have multiple communication interfaces.
- **Density Variation**
  The density of nodes in the VANET is not uniform. For example, in an urban environment the density is much higher than in rural areas. The number of vehicles in an intersection or in a traffic jam is more important than in another area where traffic is often fluid. In addition, the density is different depending on the night or the day, and / or peak or break hours. This density diversity makes it difficult to design routing protocols.
- **Network partitioning**
  This problem mainly occurs when the node density is low. Then, the vehicles move in isolated and non-connected groups. Therefore, it becomes difficult in this case to ensure end-to-end communications.

From the above characteristics, it is evident that designing a suitable routing protocol for the VANET is a big challenge. In addition, the presented behaviors make the MANET routing algorithms unsuitable for the VANET [3]. Hence, routing in the VANET has been the subject of many research works and several protocols have been proposed [4][5][7][8][9][10]. Based on the path creation manner, as well as the maintenance of routes, we can classify the VANET routing protocols into two major categories: hierarchical and non-hierarchical protocols. The aim of this paper is to study the impact of the

VANETs properties on all routing protocols.

The remainder of this paper is structured as follows. Section 2 deals with the classification of the routing protocols. Section 3 presents the simulation results and gives a comparison of the various algorithms. In Section 4, we conclude the paper.

II. Routing Protocols in VANETs

Routing is an important mechanism for the VANET, through which vehicles can communicate together, even if they are not in a direct communication range. To route a message, each protocol possesses a specific strategy to find and maintain a path. Based on this specificity, we can classify the VANET routing protocols into two major categories: hierarchical and non-hierarchical protocols.

A. Non - Hierarchical Protocols

This family of protocols is known as uniform or flat routing protocols which consider that all the nodes are equal, in the same hierarchical level, having the same roles and functions. Therefore, no hierarchy is defined between the network nodes. Each node sends and receives routing control messages [11]. Based only on its position, the node takes a decision to route packets. They are further divided into two classes: topology-based routing protocols and geographical position-based protocols.

1) Topology Based Routing Protocols

There are three routing categories that define this family, which are proactive, reactive and hybrid routing protocols.

(a) Proactive Routing Protocols

In proactive protocols, each node keeps knowledge of the entire network topology. This image is updated periodically or every topological modification by an exchange of control messages. Routing tables are maintained through these packages and routes are determined on the basis of this knowledge [12]. The proactive routing protocols are investigated as follows [13]:

- Global State Routing protocol (GSR)
  The GSR [14] is a link-state protocol where each node knows the global network topology saved in the routing table, which enables it to calculate routes and reach each destination. Unlike other protocols, the GSR nodes do not broadcast their links-state to all the network nodes, but only send its neighbors. This link-state includes the delay to reach every neighbors node. Consequently, the rate of control packets flooding in the network can be reduced. However, due to the high mobility of nodes that provide instability of links, the control overhead can increase.
- Destination-Sequenced Distance-Vector (DSDV)
  The DSDV [15] is a distance vector protocol, where each node maintains a routing table containing information about all reachable destinations. This information includes the intermediate nodes used to join the destination, the number of hops between the source and the destination node as well as the Sequence Number (SN) stamped by the recipient node, which can be an intermediate node or the destination node itself. The SN is used to differ the novel established route from the old one. Each node sends, periodically, its routing table to its neighbors. Other update packets are also sent after changing in the network topology. These packages include only the routing information affected by this variation.
  Once a node receives an update packet, it compares it with the existing information stored in its routing table. An updating in the entire routing table starts if the received information is newer with a larger sequence number or if they have the same sequence number but with a shorter distance (lower hops number). Nevertheless, the routing problem, in terms of performance, is that the DSDV engenders a large volume of control packets and consumes a large part of the available bandwidth.
- Optimized Link State Routing (OLSR)
  The main goal of the OLSR [16] is to provide the shortest possible path to reach a destination in terms of hops number based on the Dijkstra algorithm [17]. Its contribution is in using the Multi-Point Relaying (MPR) method. The idea behind this method is as follows. To reach all of its 2-hop-link neighbors, each node builds a set of nodes called the MPR. Every MPR node is used to route and forward the received messages. The other neighbors which are not MPRs can only read and execute packets.

(b) Reactive Routing Protocols

These protocols are known as on-demand routing protocols because the routes are established only when a node wants to join a destination and only the used routes are maintained [12]. In this case, unlike proactive protocols, an additional delay is required at the beginning of each search; i.e., when a node intends to transmit packets, a route discovery phase is initiated by broadcasting a route search message. Any node that receives this message and does not have information about the destination broadcasts the message. Consequently, a route search packet is transmitted from point to point in all or part of the network. This mechanism is called the flooding technique [18]. The reactive routing protocols are reviewed as follows:

- Dynamic Source Routing (DSR)
  This protocol uses the source routing technique in which the source node includes the complete route in the packet header to reach the destination node [19]. Therefore, the intermediate nodes do not need to update the information on the crossing path. The DSR is based on two phases that are the route discovery and the road maintenance.
- Ad hoc On-demand Distance Vector (AODV)
  The AODV [20] uses the number of hops as a metric to select an available route. Like the DSDV, this reactive protocol utilizes the principle of the sequence number in order to use the most new or fresh roads. There are three types of packets utilized by the AODV which are: the Route REQuest (RREQ) packet, the Route REPly (RREP) packet and the Route ERRor (RERR) packet. In addition, the AODV invokes a HELLO control packet that verifies the route connectivity. Like the DSR, the AODV uses two mechanisms which are the route discovery and the road maintenance. While the first step is used to find a route to reach a destination, the second mechanism is necessary to detect

and announce broken links caused by the mobility of nodes.

(c) Hybrid Routing Protocols
Hybrid protocols combine the two previous categories. A proactive technique is used in a limited network area around the source node where the number of hops is not more than four hops. Otherwise, the reactive method is used for the distant nodes [21]. The advantage of the hybrid protocols is that they adapt better to large networks. However, this type of protocol combines the cons of proactive and reactive routing protocols such as the regular exchange of control packets and the flooding of the whole network in order to find a route and join a distant node.

- Zone Routing Protocol (ZRP)
It divides the network into different zones. For each node, it defines a routing zone expressed in a maximal number of hops. Inside this area, the ZRP uses a proactive protocol; and outside of this routing zone, it uses a reactive protocol [22]. Based on various comparative and behavioral studies of topology-based routing protocols in the VANET [23][24][25], the previous protocols are compared and tabulated in Table 1.

2) Geographical Position Based Protocols

Geographical protocols are based on two phases: the location of the destination node and the routing of packets to this node [26]. However, these protocols require a node location service for the routing packets in the network. Yet, most of these protocols generate a lot of control packets which can increase the network congestion. Various protocols belong to this type.

(a) Greedy Perimeter Stateless Routing (GPSR)
The routing technique of the GPSR [27] is based on two phases. The first step is to select of the next transmitter node which will have the role to retransmit packets. This procedure is based on the position information of the neighboring and destination packet. This step is necessary to choose the nearest node to the destination. The second part of the GPSR is to get around the obstacles as well as the empty geographical areas where no transmitter node exists.

(b) Movement-based Routing Algorithm (MORA)
To take an adaptable retransmission decision, MORA [28] used the position and movement direction of vehicles. This method takes into consideration the dynamic changes in the network.

(c) Vehicle-Assisted Data Delivery (VADD)
The VADD [29] uses the predictable movement of vehicles to take a retransmission decision. It particularly uses the information on the traffic road to estimate the transmission delay. Therefore, the packets will be routed along a path with the lowest time.

(d) Greedy Traffic-Aware Routing protocol (GyTAR)
The main goal of this protocol is to route data to the nearest node considering the specific factors to this kind of network environments. The GyTAR [30] protocol assumes that each vehicle knows its current position using the GPS service. In order to make routing decisions, a source node has to know the destination position.

(e) Urban Multi hop Broadcast Protocol (UMB)
In order to reduce collisions problems and effectively utilize the bandwidth, the UMB [31] is based on the multi-hop diffusion algorithm for inter vehicular networks. Unlike the flooding protocols, the UMB assigns a sending packet process to the most distant nodes without knowing any information about the network topology.
The UMB is based on two phases: the first is called directional broadcast where the vehicle selects a source node for relaying a data without any information about the network topology. The second is called intersection broadcast where the packet disseminates in all directions. The main advantage of the UMB protocol is that it performs well in terms of multi-hop broadcast reliability in urban channels.

(f) Anchor-based Street and Traffic Aware Routing (A-STAR)
This protocol uses particularly the information about city bus routes in order to identify a route anchor with a high connectivity for routing packets. The A-STAR [32] adopts a routing approach based on the anchor, which reflects the characteristics of the streets. A point is associated with each street according to its capacity (large or small Street serviced by a number of different buses). Information about the roads provided by buses give an idea on the

TABLE I. A COMPARISON STUDY OF TOPOLOGY BASED ROUTING PROTOCOLS IN VANET.

	Pros	*Cons*
DSR	-Beacon less. -It has small overload on the network. -It reduces load on the network. -No periodical update is required in DSR.	- The control overhead is high. -Unnecessary flooding burden the network. -In high mobility pattern, it performs worse. -Unable to repair broken links locally.
AODV	-It uses destination sequence number. -It reduces excessive memory requirements and the route redundancy. -AODV responses to the link failure in the network. -It can be applied to large scale ad hoc network.	-More time is needed to establish a route compared to other approaches. - It provide a heavy control overhead. -It consumes extra bandwidth.
GSR	-Packet delivery ratio of GSR is better than AODV and DSR. -GSR is scalable than AODV and DSR.	- It neglects the situation like sparse network where there are not enough nodes for forwarding packets. -GSR shows higher routing overhead than GyTAR because of using hello messages as control messages.
DSDV	-It solves routing loop problem. -It reduces the count to infinity problem. -It maintains only the best route.	-It takes up a large volume of available bandwidth. -It is unsuitable for high density and dynamic networks.
OLSR	-It is suitable for high density and dynamic networks. -The number of transmission is less.	-The control packet overhead is high.
ZRP	-It reduces the control overhead.	-It combines the drawbacks of reactive and reactive protocols.

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charge of the vehicular network in each street. This gives an image of the city in different times.

(g) Distributed Vehicular Broadcasting (DV-CAST)
The DV-CAST [33] is designed to be used for a multi-hop routing technique. This protocol shows three scenarios of movement for broadcasting vehicles: dense traffic scenario, sparse traffic scenario, and regular traffic scenario. Lots of studies have demonstrated that the DV-CAST provides an elevated control overhead and delay in end-to-end packet transmissions.
Their used essential characters, illustrated in different survey papers, deal with position-based routing protocols in the VANET [34][35]. The previous protocols are compared and presented in Table 2.

TABLE II. A COMPARISON STUDY OF POSITION BASED ROUTING PROTOCOLS IN VANET.

	Pros	*Cons*
GPSR	-To forward the packet a node needs to remember only one hop neighbor location. - Forwarding packet decisions are made dynamically.	- For high mobility characteristics of node, stale information of neighbors position is often contained in the sending nodes neighbor table. - Though the destination node is moving its information in the packet header of intermediate node is never updated.
MORA	-It performs well in high dynamic topology.	- Complex metrics used to forwarding packets.
VADD	- It is suitable for multi-hop packet transmitting. - Packet delivery rate is high.	- Traffic road is high.
GyTAR	- Number of transmission is less. - Efficient for high dynamic network.	- Control packet overhead is high. - It is on the basis of a roadside units to define vehicle number.
UMB	-It performs well at high packet loads and vehicle traffic densities. - It solves packet collision problem.	- It broadcasts message without any topology information that can increase rate of dropped packet.
A-STAR	- In low traffic density, A-STAR ensures for finding an end-to-end connection. - A-STAR uses a new local recovery strategy which is more suitable for city environment. - Path selection of A-STAR ensures high connectivity though its packet delivery ratio is lower than GSR and GPSR.	- The packet delivery ratio of A-STAR is lower than GSR and GPSR. -To find a path from source to destination it uses static information based on city bus routes which causes connectivity problem on some portion of streets.
DV-CAST	-By using flag variable check whether the packet is redundant or not.	- Control overhead is high. - End to end data transfer delay is high.

B. Hierarchical Routing Protocols

In this type of routing protocols, the neighboring vehicles form a group of nodes or a cluster. Each cluster is managed by a leader node, called the cluster-head [36]. Each cluster head is responsible for managing the nodes, not only in the same group but also between the neighboring clusters. The clustering operation and the manager node selection are of two necessary steps. Several protocols are classified under this routing type, namely:

1) Hierarchical Cluster Based (HCB)
This protocol is designed especially for high mobility networks and it is based on a two-layer communication architecture. While in the first layer the nodes can communicate with each other via a multi hop path based on their unique interface radio, there exist [37] nodes in the second layer that also have another radio communication interface.

2) Cluster Based Location Routing (CBLR)
For this protocol, each cluster head maintains a routing table containing the addresses and geographical locations of the nodes in its own group and for the neighboring clusters [38]. When a source node wants sending a data to a destination, the leader node checks if the destination is in the same group or not. If it is, it sends the packet to the nearest neighbor of the destination.

3) Cluster-Based Directional Routing Protocol (CBDRP).
To form a cluster, this protocol uses the vehicle movement direction as a metric. Consequently, the nodes get the same direction form a group [39]. The source node sends the packet to its cluster head, which forwards the message to the leader node of the destination group, which in turn transmits it to the destination.

4) Cluster Based Routing Protocol (CBRP)
The CBRP [40] uses geographical information to form a cluster. To locate a node, the geographical areas are divided into a grid form. The node existing in a grid will be selected as a cluster head., The selected node must broadcast a LEAD message to inform its neighbor vehicles or a LEAVE message if it leaves the grid. Both the LEAVE and LEAD messages contain the position of their grid.
On the basis of diverse behavioral studies of hierarchical protocols in the VANET [41][42], the above cited methods are compared and presented in Table 3.

TABLE III. A COMPARISON STUDY OF HIERARCHICAL ROUTING PROTOCOLS IN VANET.

	Pros	*Cons*
HCB	- Intra-cluster routing is performed independently in each cluster. -Cluster heads exchange membership information periodically to enable inter-cluster routing.	- Number of retransmission is high. - packet loss rate is high.
CBLR	-It is suitable for high mobility network. - Digital map is used. -Control packet overhead is low.	- Number of retransmission is high.
CBDRP	-Link stability problem solve in VANET. -Reliable and rapid data transfer.	-Control packet overhead is average. -Number of retransmission is high.
CBR	-Routing overhead is less.	- It doesnt consider velocity and direction of a vehicle.

Fig. 2 summarizes the taxonomy of different routing protocols in the VANET.

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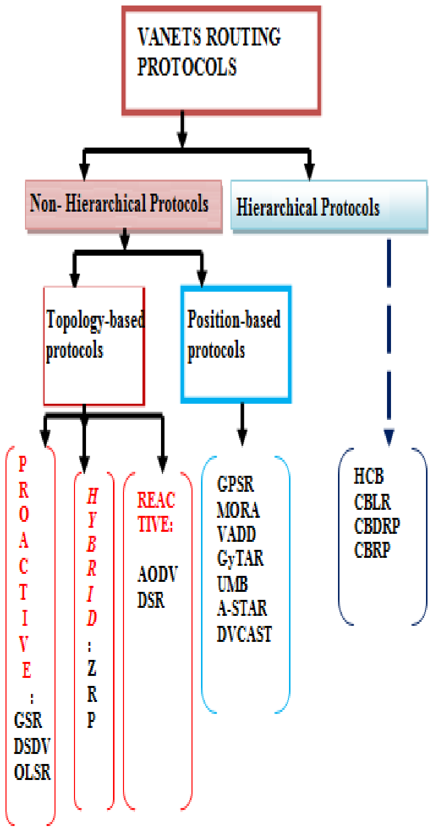

Figure 2. Toxonomy of different routing protocols.

As one can see in Fig. 2, a VANET routing protocol may be classified according to various criteria reflecting a fundamental design.

III. Simulation Results and Analysis

Unlike the previous part, where we compared the various routing protocols of the same category based on their important parameters, in this section we compare the different routing categories on the basis of simulation results. To achieve this goal, we chose from each routing family a single protocol. Consequently, we evaluated the performance of the AODV [20], the DSDV [15], the GPSR [27] and the CBRP [40] routing protocols using OMNET++ [43] and MATLAB [44] tools.
We selected three performance metrics, which are the average of the end-to-end delay, the throughput, and the Packet Deliver Ratio (PDR).

- The end-to-end delay (E2E delay): It defines all the delays caused during the routing process, such as transmission/re-transmission delays at the MAC layer, the transfer delay, and the route discovery delay.
- Throughput: The throughput is the most important metric because we are concerned with the number of transmitted messages. It is described as the total number of received packets at a destination out of the total simulation time.
- Packet deliver ratio (PDR): The rate of the number of delivered packets to the best destination defines the PDR.

The simulation parameters are listed in Table 4.

TABLE IV. Simulation parameters.

Parameter	*value*
Transmission rate	54Mbps.
Simulation time	200-1400s.
Playground Dimensions	1300m x 1300m.
Routing protocols	AODV,DSDV,GPRS, and CBRP.
Transmission range	150m.
Number of nodes	30.
Mac type	IEEE 802.11p

A. E2E Delay

Fig. 3 depicts the E2E delay average measured for the previously discussed methods with a variation in the simulation time from 200 to 1400s. In this routing case, the number of vehicles is fixed to 30. We can notice that at [200,800], and despite the increase in the E2E delay average value of the GPSR from 5% at 500 to reach 13% at 800 s, it outperforms the AODV, DSDV and CBRP protocols. Nevertheless, at [800, 1400], the CBRP demonstrates a good behavior. On the other hand, the topology-based routing protocols represented by both the AODV and DSDV methods show a bad performance in terms of E2E delay in the entire simulation time.

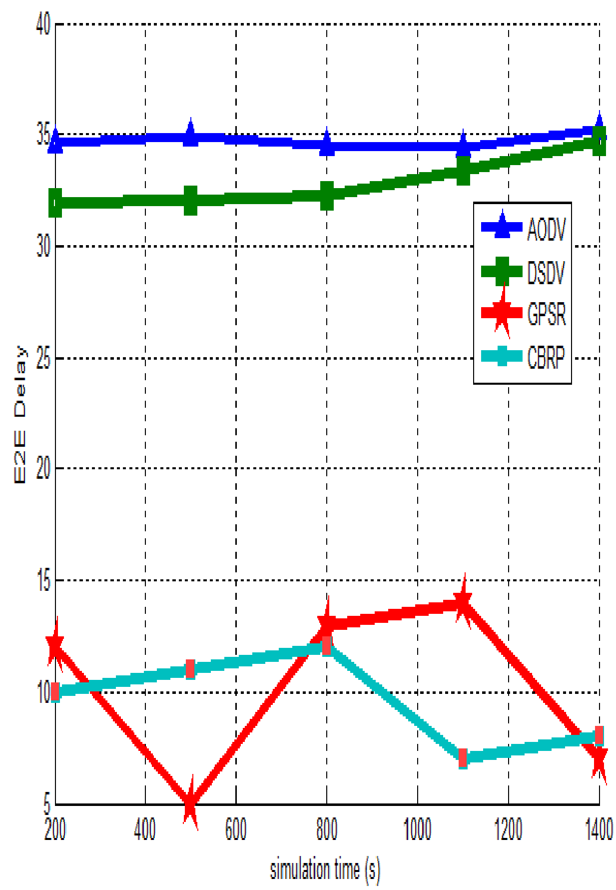

Figure 3. E2E Delay vs. simulation time.

B. Throughput

In Fig. 4, the results of the measured throughput for the four methods depend on the simulation time. The results indicate a more efficient behavior of topology-based routing protocols in comparison with the GPSR and the CBRP when the simulation time grows. As illustrated in the figure below, the AODV exhibits the highest throughput value in spite of the fluctuations from different simulation times.
We observe also that although its throughput value is mostly half of the AODV value, the DSDV shows good results compared to the GPSR and CBRP protocols which demonstrates a bad behavior in terms of throughput rate.

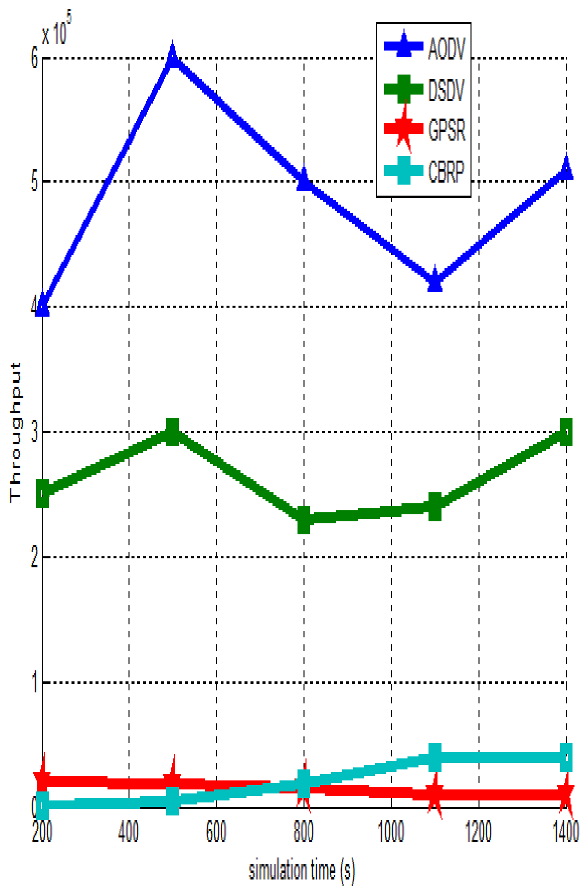

FIGURE 4. THROUGHPUT VS. SIMULATION TIME.

C. Packet Delivery Ratio (PDR)

In Fig. 5, the PDR of the AODV, the DSDV, the CBRP and the GPRS are presented when the simulation time is varied from 200 to 1400s. It can be seen that the CBRP, the DSDV and the AODV demonstrate a better performance than the GPSR, with a slight difference counted for the CBRP.
As compared to the cluster-based routing protocol and the topology-based methods, the GPSR exhibits the lowest performance level. The reason behind the bad behavior in terms of packet delivery ratio is due to the feature of the GPSR in which it takes into consideration the geographical position of nodes that cannot be an ideal metric. However, the clustering technique provides a more stability for the CBRP. As a result, Fig. 5 shows a PDR over 1 for the CBRP.

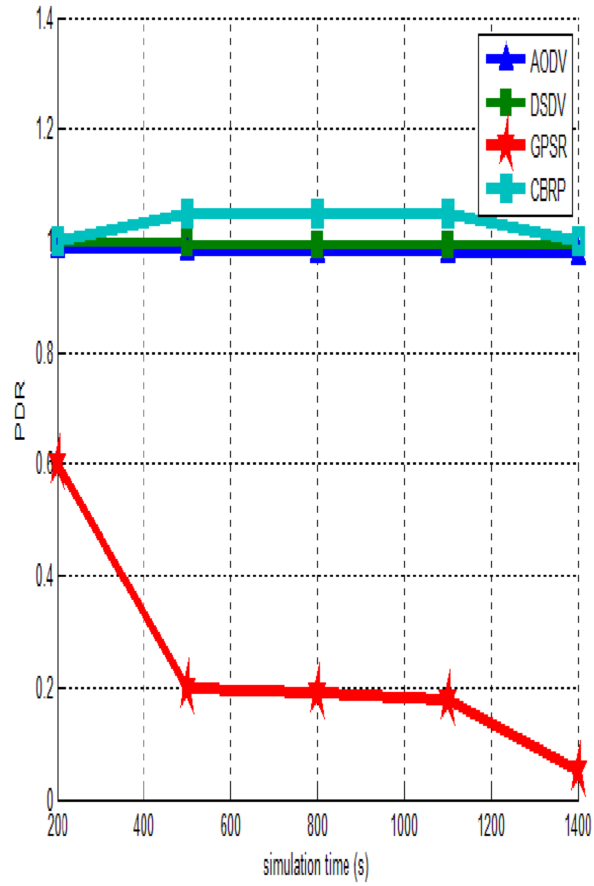

FIGURE 5. PDR VS. SIMULATION TIME.

Table 5 presents a numerical comparison of the AODV, DSDV, CBRP and GPSR routing protocols in terms of throughput, E2E delay and packet delivery ratio in the cases where the simulation time has minimum and maximum values.

TABLE V. NUMERICAL COMPARISON BETWEEN AODV, DSDV, CBRP, AND GPSR PROTOCOLS.

	Simulation time is 200s			Simulation time is 100s		
	Throughput (byte/s)	E2E Delay	PDR	Throughput (byte/s)	E2E Delay)	PDR
AODV	400000	34.9%	1	500000	35%	1
DSDV	250000	31%	1	300000	34.8%	1
GPSR	20000	11%	0.6	10000	7%	0.1
CBRP	520	10%	1	40000	7.5%	1

IV. CONCLUSION AND FUTURE WORK

The key difference of Vehicular Ad hoc Network (VANET) and Mobile Ad hoc Network (MANET) is the exceptional mobility pattern and quick variability variable of network topology. Thus, the most important aim of this paper is to categorize different mobile ad hoc routing protocols and to evaluate these methods in the VANET. In this paper, we have

reviewed and compared the different routing categories. From the results of our comparative study, we have examined the topology-based routing protocols, the AODV and the DSDV, against the position-based routing protocol, the GPSR, as well as the cluster-based routing protocol, the CBRP. We have demonstrated that the GPSR outperforms the AODV, the DSDV and the CBRP in terms of E2E delay with a low simulation speed. Nevertheless, the CBRP demonstrates a good behavior when the simulation time grows. We have also found that the topology-based routing protocols show a bad performance in the entire simulation time.
On the one hand, the results of the measured throughput have depicted a more efficient behavior of topology-based routing protocols in comparison with the GPSR and the CBRP despite the fluctuations from different simulation times. On the other hand, the GPSR have exhibited the lowest performance level in terms of packet delivery ratio compared to the CBRP, the DSDV and the AODV. From this study, it is evident that each routing protocol category has its network specificity, which makes it efficient in one case and inefficient in another.
The novelty of this paper is to compare and evaluate all the categories routing protocols and show the impact of the VANET properties on each class.
As a future work, we intend to improve the AODV protocol to make it more efficient and effective in vehicular networks.

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