An Advanced Comparative Study of MANETs Routing Protocols Under Varied Number of Nodes and Mobility Rate

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Abstract —The development of wireless technology has offered interesting perspectives in the field of telecommunications which has allowed the manipulation of information through mobile nodes equipped with wireless communication interfaces and with limited characteristics (low storage capacity, autonomous source of energy, limited bandwidth, etc.). In a mobile ad hoc network, , generally called MANET, managing the data routing is to ensure a strategy that guarantees at any time the connection between any two nodes in the network, it must consider changes in topology and other characteristics of the network (bandwidth, number of links, network resources... etc). In this paper, we focus on the data routing issue that represents the major challenge in the deployment of this networks, we present the theoretical aspects of all the different routing protocols classes, we apply an advanced comparative study on these protocols performance and we illustrate some network topologies with the results obtained through simulation analysis.

Index Terms—MANET; VANET; WSN; IoT; modelization; routing protocols; performance analysis

I. Introduction

Advances of mobile environments and IoT has enabled the development of applications offering the network nodes a free mobility and placing no restriction on the location of the end users to access the information without the use of wired infrastructure. In an Ad-hoc network, each mobile node is totally autonomous in its movement, its operation and its participation in data routing through the use of wireless interfaces that form a sort of global architecture usable as infrastructure of the network. Since the propagation radius of the node transmissions is limited, and in order to guarantee the connectivity of the ad hoc network, mobile nodes can often be used as intermediate nodes and participate in the routing of the packets from the source to the destination according to a routing strategy that respects the different used metrics.

For several years great effort has been devoted to the study of mobile environment and particularly MANETS. However, very few publications can be found in the literature that discuss and analyze the performance of routing protocols of all classes in the same work. This paper aims to present an advanced comparative study of the most performant routing algorithms in the literature covering all routing protocols classes and according to two main factors that influence the deployment of MANETs: the density of nodes in the network and their mobility rate. While we refer to our earlier work [1] the focus is different, the originality of this work lies in the use of more performance metrics and comparative schemes. The remainder of the paper is organized as follows:

Section II describes the state of the art, Section III discusses the challenge of data routing in MANETs and our classification of routing protocols, experimental results are presented in Section IV; while the conclusion is reported in Section V to summarize the results of this work and to draw conclusions.

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II. State of the Art

A. Modelization of MANETs

MANETs are used to provide wireless communication between heterogeneous devices equipped with wireless transmitters and receivers using antennas that can be omnidirectional (broadcast), highly directional (point to-point), or a combination of these two types [2], [3]. In a mathematical concept an ad hoc network, in an instant t, can be represented by an undirected graph:

$G_t = (V_t , E_t)$, where:

V_t: Represents the set of the nodes.

E_t : Represents the set of links between these nodes (Fig. 1).

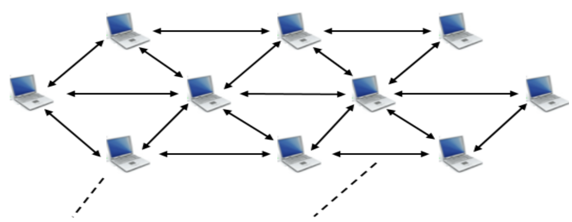

Fig. 1. Architecture of Mobile Ad Hoc Networks (MANETs)

For each mobile node (i), the set of neighbors at one-hop is represented by:

$$N^1 = \{j \in V: (i,j) \in E\} \quad (1)$$

While the set of neighbors at two-hop is designated by:

$$N^2(i) = \coprod_{j \in N^1(i)} N^1(j) - N^1(i) - \{i\} \quad (2)$$

The degree of the vertex i which designates the number of arcs that have the station i for origin or for destination is denoted by:

$$\mathrm{d(i)} = |\{x \in N^1(i): (i,x) \in E\}| \quad (3)$$

B. Application fields of MANETs

The special feature of Ad hoc network is that they don't require any fixed installation which makes their deployment easy and fast [5]. These networks are used in tactical applications such as rescue, military or explorations and also in some civilian applications that have emerged:

- Emergency services: search and rescue operations with the aim of replacing the wired infrastructure.
- Collaborative works and communications for example in a meeting or conference.
- Commercial applications: electronic payment, mobile access to the Internet or guide service according to user position.
- Sensor networks: Sensors, which measure the physical properties of environments (such as temperature, pressure, etc.), are dispersed by hundreds or even Thousands on site, perform their measurements and send the results to a station via ad hoc routing across the network.

In the context of computing, ad hoc networks can be used to establish links between various components. In this case, we talk about PAN (Personal Area Network) rather than LAN (Local Area Network).

C. MANETs Specefic Characteristics

MANETs can be deployed without infrastructure and with distributed control [5]. The main difference with a wired network lies in the role played by the nodes, in wired networks there are two categories of entities: the terminals and those in charge of the routing whereas in MANETs all nodes are actively involved in the routing process. These networks are characterized by:

- A dynamic topology due mainly to nodes mobility and to radio environment changes.
- Limited bandwidth that affects the volume of information exchanges.
- Limited physical security due to the vulnerability of the traditional communication medium (listening attacks, denial of service,…)
- A high error rate due to the use of a radio environment and asymmetrical links.
- Energy constraints due often to modest energy sources of nodes
- Variable connections and interference between network nodes that increase the number of errors on the transmission and impose performance degradation.
- Mobility of the nodes in the network causing in some cases breaks of roads
- Multihop communication: MANETs are qualified by multihop since several mobile nodes can participate in data routing and serve as intermediate routes.

III. Routing in Manets

A. Data Routing Challenges in MANETs

Ad hoc networks are characterized by their ability to route data packets through multi hop communications without the help of base stations used in cellular communication [6]. The challenge in these networks is to adopt routing methods that can be used with large number of nodes in a modest computing and backup capacities environment.

Flooding or pure diffusion consists in propagating data or control packet through the entire network. A node that initiates the flood sends the packet to all its direct neighbors, then, receptive nodes rebroadcast it to all their neighbors until the packet reaches its destination. It should be noted that the flooding technique is very expensive especially when the network is very dense, that is why routing protocols try to minimize the propagation of the flooded packets by adding other diffusion parameters.

B. Conception of MANETs Routing Protocols

Since MANETs environment is dynamic, network topology can change frequently. Therefore, the design of any routing protocol should have as objectives:

- Network load minimization: network resource optimization engenders two other sub-problems that are routing loop avoidance, and preventing traffic concentration around some nodes or connections.
- Support for reliable multi-point communications: the fact that the paths used to route data packets can change should not have a problem with proper routing of data. The elimination of a link due to breakdown or to mobility should not cause a high increase of latency.
- Optimal routing: the routing strategy must create optimal paths and be able to take into account different cost metrics (bandwidth, number of links, network resources, end-to-end delays, etc.). If the construction of optimal paths is a hard problem, maintenance of such paths can become even more complex, the routing strategy must ensure efficient maintenance of roads with the least possible cost.
- Latency time: the quality of latency and path times must increase when the connectivity of the network increases.
- High reactivity: Adapt to topology changes quickly by proposing new routes

C. Classification of MANETs Routing Protocols

Due to their particular properties, MANETs use specific routing protocols that can be classified according to network topology, routing strategy and the role of mobile nodes in data routing [7]:

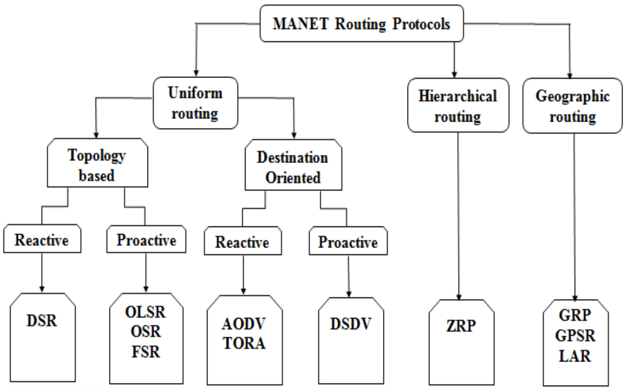

Fig. 2. Classification of MANETs routing protocols

1) Proactive routing protocols:

These routing protocols try to maintain the best existing paths to all possible destinations at each node of the network by using a regular exchange of control messages to update the routing tables whenever the network topology changes [7]. This approach guarantees to have a route to each destination immediately when a packet is ready to be sent. The two main methods used are the Link State method and the Distance Vector method.

However, the Link State approach requires that each node must maintain an updated version of the complete network topology, which needs a large storage space and involves an overload of exchanged control packet in the case of dynamic networks. Furthermore, no implemented algorithm based on the principle of Link State, could completely eliminate the creation of temporary routing loops.

2) Reactive routing protocols:

These protocols search routes to a new destination on demand and no control message can load the network for unused routes which do not waste network resources [7], [8]. Most of the algorithms used in this class are based on the backward learning mechanism. Reactive protocols induced slowness due to path searching process, which can degrade the performance of interactive applications (distributed database applications). In addition, it is impossible to evaluate the quality of the path (in terms of bandwidth, delays, etc.).

3) Hybrid routing protocols

Hybrid routing protocols combine both approaches: proactive routing (to get information at two-hops) and reactive (to search routes) [7]. This category adapts well to large networks but it cumulates the disadvantages of both approaches (periodic control cost of new route establishing ...)

4) Hierarchical routing protocols:

These protocols use group-based routing strategies to facilitate routing management tasks such as packet transmissions and bandwidth allocation by dividing the network into a set of connected but independently controlled groups in a way that any node in the network can reach any other node using the intermediate nodes [9], [10].

Managing members of a dynamic group allows a node to join a group, to leave that group or to move elsewhere. Group communication ensures independence of the location which is very suited to reconfigurable network topologies, such as mobile site architectures.

5) Geographic routing

Geographic routing is based on the use of position geographic coordinates (provided by GPS) to find routes to the destination [10], [11]. The geographical coordinates of the nodes are included in the packet to send, and then used by the intermediate nodes along with those available in their routing tables to retransmit the packet until it reaches the destination. Network management becomes simple with the node location based topology but the disadvantage is that each node must have a vision of its neighboring nodes locations.

D. Review of MANETs Routing Protocols

In this part, we present the most popular MANETS routing protocols [10]-[14] and their routing strategies on which a performance study will be applied in the next part of this article.

- **DSR** (Dynamic Source Routing) is a reactive routing protocol [15] [16]. This protocol creates the routes on demand by using the technique of source routing in which the source includes in the packet header the complete route through which a packet must pass to reach its destination. The intermediate nodes between the source and the destination do not need to keep updated the information on the crossing route since the complete route is inserted into the packet header. DSR is composed of two mechanisms: route discovery and maintenance of road, the first allows searching necessary routes for the application, while the second ensures the maintenance of all routes during their use.

- **OLSR** (Optimized Link State Routing)] is a proactive link-state routing protocol [17] [18], it introduces the concept of Multipoint relays (MPR) to optimize the distribution of topological messages on the network. In OLSR, each node has a particular set of nodes that are the only ones allowed to retransmit these topological messages. These MPR nodes are selected from the one hop neighbors to allow the access to all neighbor nodes in two hops.

To select a group of neighbors that form its MPRs, a node must have, in addition to the list of its direct neighbors, the list of its neighbors in two hops. This information is obtained through the periodic exchange of HELLO packets between direct neighbors which contains:

- The list of neighbors from which the node received a HELLO packet.
- The list of neighbors accessible by a bidirectional link.

- The list of neighbors that the node selected as MPRs.

- **AODV** (Ad hoc On-demand Distance Vector) is a protocol that creates the routes when needed based on the principle of sequence number to use the newest routes [15] [19]. In addition, it uses the hop count as a metric to choose between several available routes. AODV uses three types of packets: RREQ (Route Request Message), RREP (Route Reply Message) and RERR (Route Error Message). In addition to these packets, AODV invokes control packets HELLO that verify the connectivity of routes.

AODV is based on two mechanisms: route discovery to find a route to a destination and route maintenance and the road maintenance to detect and report road errors possibly caused by the mobility of nodes. This protocol uses flooding to discover the roads which can generate huge traffic control and add an initial delay when sending the first packets to an unknown destination. A disadvantage of this protocol is that there is no generic message format: each message has its own format: RREQ, RREP, and RERR. The use of sequence numbers also creates some complexity, but has the advantage of greatly reducing unnecessary retransmissions.

- **DSDV** (Destination-Sequenced Distance-Vector) is a routing protocol based on the distance vector mechanism [18]. Each node maintains a routing table containing information about the accessible destinations on the network, this information includes the following node used to reach the destination, the number of hops to the destination node and the sequence number that distinguish the new routes of old. Each node sends periodically its entire routing table to his neighbors, other update packets are also sent in response to a change in the network topology which includes only the entries in the table affected by the change and aim to propagate routing information as quickly as possible.

When a node receives an update packet, it compares it with the existing information in its routing table. Any entry in the table is updated if the received information is newer (with a larger sequence number), or if they have the same sequence number but with a shorter distance.

In DSDV protocol, a mobile node should wait until it receives the next update initiated by the destination in order to update the entry for this destination in the distance table. Therefore, the reaction of DSDV to changes in the topology is considered slow. Furthermore, this protocol causes significant load control in the network because of the transmission of update packets periodically or following events.

- **ZRP** (Zone Routing Protocol) is a hybrid protocol [20]; each node defines an area around him limited in the number of hops between the center and the border nodes in which he will use his proactive protocol. A second reactive protocol operates outside of this zone, which allows searching routes to an outside destination. Thereby, ZRP defines two types of protocols; one is locally operated, while the second operates between the areas:

- IARP (Intra-zone Routing Protocol) offering optimum routes to the destination that is within the area at a given distance, and any change is reflected in the interior only.
- IERP (Interzone Routing Protocol) which is responsible to find routes on demand for destinations outside of a zone.

- **GRP** (Geographic Routing Protocol) is a position based routing protocol that uses the concept of geographic routing where each node determines its position based on different positioning schemes such as GPS and GPRS [22].

Routing in GRP is done in two ways:

- Greedy forwarding where the information is sent to the nearest neighbor of the destination node.
- Perimeter routing which uses the concept of planar graph transversal.

In the position based routing there is no need to maintain routing tables continuously; moreover, it gives the better performance in dynamic topologies because the packets are forwarded to its destination according to its position [22].

IV. SIMULATION

The simulation allows analyzing routing protocols performance according to different environment factors such as the number of mobile nodes, the mobility speed, the network territory and the distribution of the nodes...

A. *Simulation Tool*

In this work, we used OPNET Modeler 14.5 (Optimum Performance NETwork) to evaluate the performance of MANETs routing protocols for the following reasons:

- Modeling the network during the design phase and visualizing problems that occur.
- Reproducing the structure of the network using the GUI and the object-oriented modeling.
- Opnet simulator uses a radio propagation model that is close to reality and based on calculating the Signal to Noise Ratio (SNR).

In our network model, each node can move randomly within the network range using the “Random Waypoint Model” as a mobility model where nodes are initially distributed randomly on the deployment field and to each node is assigned a destination and a mobility speed. New destinations are selected from a uniform distribution regardless of the previous destinations and speed rate.. Simulation parameters are listed in Table I.

TABLE I: NETWORK SIMULATION SETUP

Parameters	Value
Operation mode	802.11a
Number of nodes	20; 100
Simulation time	60 minutes
Routing protocols	**DSR, OLSR, AODV, DSDV, ZRP, GRP**
Addressing mode	IPV4
Mobility rate	2 m/s; 10 m/s
Simulation area	1200 m*1200 m

Node movement model	Random waypoint
Data rate (Mbps)	11
Bandwidth (Mbps)	11
Data packet size	128 * 8 bits
Transmit power (w)	0.10
Simulator	OPNET 14.5

B. Performance Evaluation Metrics

Simulation metrics are used as indicators to describe the simulation results and to evaluate the efficiency of routing protocols. In this work, our analysis is done by varying number of nodes and mobility speed [23] on the basis of the following performance metrics:

- Routing traffic: the number of transmitted packets in the network.
- Delay: The time between transmission and reception of a packet [26], this metric is calculated by the following formula:

$$T_{avg} = \frac{\pi \sum_{i=1}^{N_r} (H_r^i - H_t^i)}{N_r} \quad (4)$$

With the following parameters:

- H_r^i : Transmission time of the packet i
- H_t^i : Reception time of the packet i
- N_r : Total number of packets received.

- Throughput: the ratio of the number of packets sent to the total number of packets. The greater value of throughput means the better performance of the protocol. This metric is calculated as follows:

$$T = \frac{L - C}{L} R f(\gamma) \quad (5)$$

where the following parameters:

- L: Packet length.
- C: Cyclic Redundancy Check.
- R (b/s): Binary transmission rate.
- $f(\gamma)$: Packet success rate.

- Packet Delivery Ratio: the ratio between the amount of incoming data packets sent by the source node and received data packets at the destination node. This metric reflects the efficiency of a protocol in delivering data packets, the performance is better when this ratio is high.
- Mobility: refers to the movement of nodes in the network, it can be low or high which causes dynamic network topology changes [23].

In order to guarantee the validity of the results obtained from our simulations, each protocol we tested in our simulations represents a particular class of our MANETs routing protocols classification (Fig. 2.)

C. Simulation Results

To evaluate the performance of MANETs routing protocols, our network model has been set up for two different scenarios of simulation under different simulation parameters:

1) First scenario: Impact of low node mobility and low network density.

In the first scenario: impact of low node mobility and low network density, we deployed 20 mobile nodes with a mobility speed of 2 m/s using the parameters mentioned in Table I.

Fig. 3. Simulation environment of the scenario 1 in Opnet

- **Traffic load:**

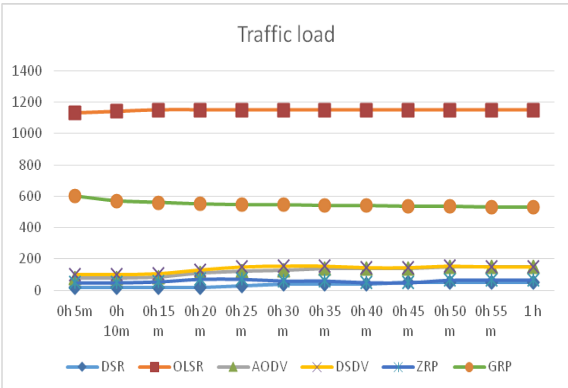

Fig. 4. Evaluation of traffic load in scenario 1

In Fig. 4. we compare the average of the traffic load between routing protocols, it can be seen that DSR shows the lowest traffic load followed by GRP and AODV while OLSR shows the highest level of the traffic load.

In small networks, DSR generates less routing traffic since the prevalence of broken links is a factor that does not have much influence. While OLSR generates more communication overhead and takes more maintenance time due to the fact of being a link state protocol that uses a table-driven approach.

- **Wireless delay:**

As can be seen from Fig. 5. ZRP protocol shows the lowest delay followed by OLSR and GRP while DSR shows the highest delay.

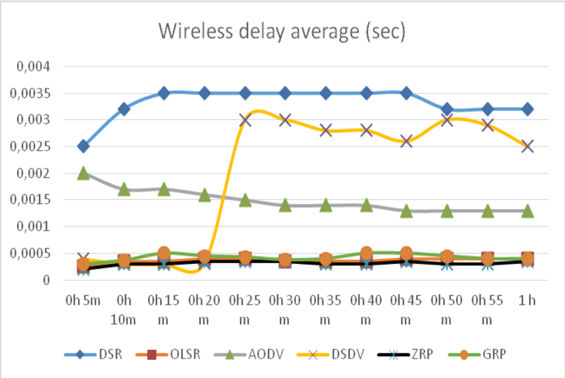

Fig. 5. Evaluation of wireless delay in scenario 1

DSR uses cached routes and most often, it sends the traffic on the obsolete routes which can lead to retransmissions and excessive delays. Thus, in networks with high traffic sources, increasing the number of connections generates worse delay. On the other hand, the DSR protocol attempts to minimize the effect of obsolete routes by using multipath links. While DSDV takes more time to converge before using a route since this protocol is based on periodic broadcasts.

- **Wireless throughput:**

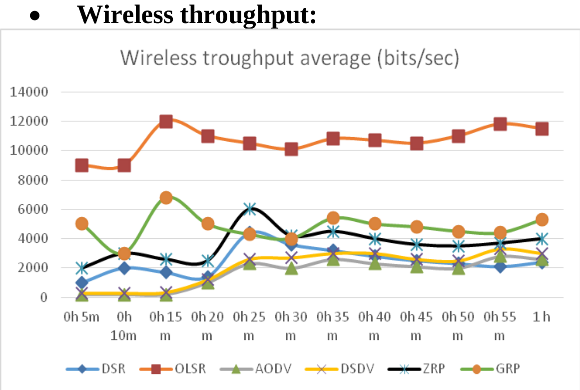

Fig. 6. Evaluation of throughput in the scenario 1

From the Fig. 6. we observe that OLSR shows the highest throughput followed by GRP and ZRP while AODV shows the lowest throughput.

As OLSR is a proactive routing protocol, routes are immediately available for traffic; this protocol maintains consistent paths in the network which results in a low delay and in a higher throughput.

- **Packet Delivery Ratio:**

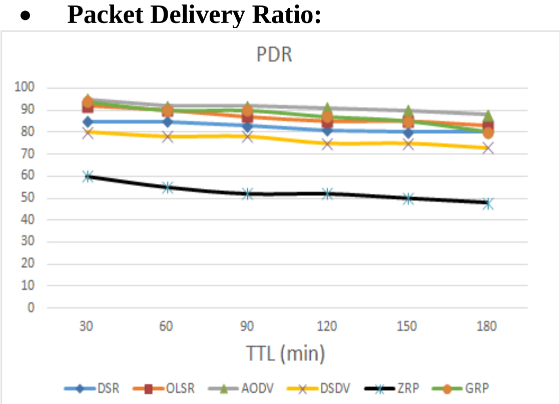

Fig. 7. Evaluation of PDR in the scenario 1

As shown in Fig.7. AODV has the overall best performance; this protocol is the improvement of DSR and DSDV and presents advantages of both of them. DSR protocol uses stale routes due to the large route cache which causes frequent packet retransmissions and a medium PDR.

2) Second scenario: impact of high node mobility and high network density.

In this scenario, we deploy100 mobile nodes with a mobility speed of 10 m/s in the same simulation environment mentioned in Table I.

- **Traffic load:**

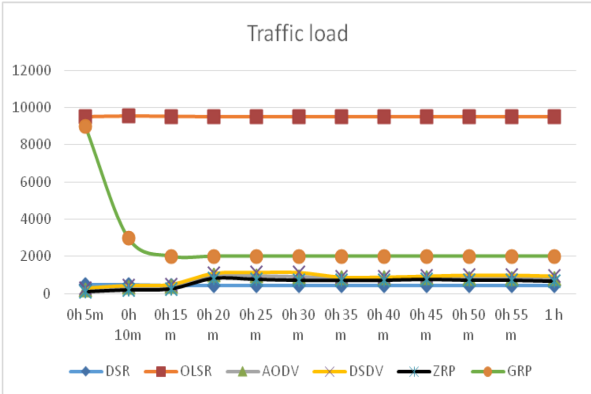

Fig.8. Evaluation of traffic load in scenario 2

It can be seen from Fig. 8. that OLSR generates the maximum traffic load followed by GRP and DSDV while DSR generates the lowest traffic load.

In GRP protocol, the traffic decreases hardly then remains almost stable during the rest of the simulation.

- **Wireless delay:**

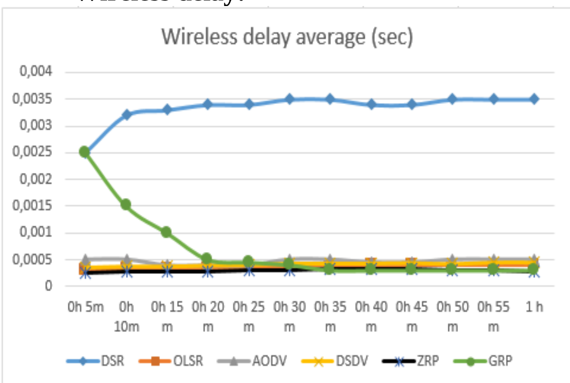

Fig. 9. Evaluation of wireless delay in scenario 2

According to the Fig. 9. we observe that OLSR shows one of the lowest delays, since it's a proactive routing protocol, the network connections are always ready whenever the application layer has traffic to transfer. The periodic updates keep the routing paths available for use and the absence of a high latency induced by the discovery process routes in OLSR explains its relatively low delay.

With a larger number of mobile nodes, the performances of OLSR compete with those of AODV. It can also be observed also that GRP offers a good delay in the case of high number of nodes.

- **Wireless throughput:**

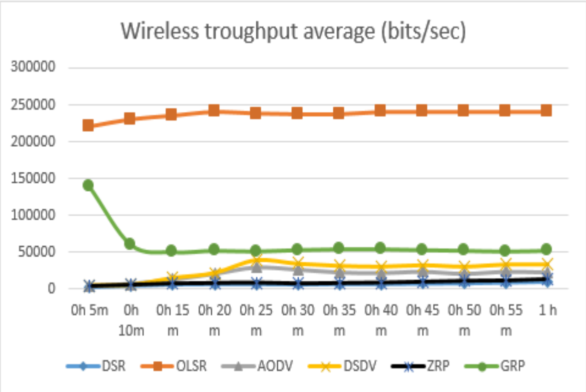

Fig.10. Evaluation of throughput in the scenario 2

In this scenario of simulation, we observe that while protocols ZRP and DSR offer a very low throughput comparing to the other protocols, the throughput of AODV drops fast because the available bandwidth is used mostly in the route searching mechanism.

- **Packet Delivery Ratio:**

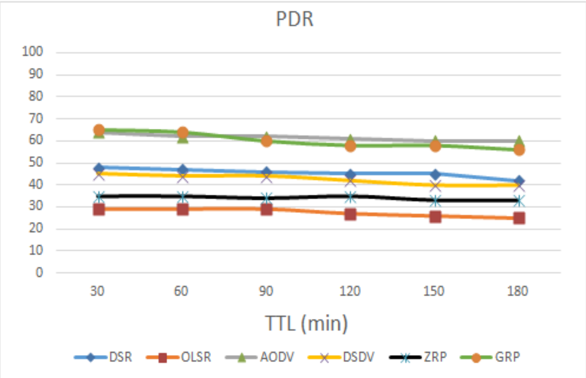

Fig. 11. Evaluation of PDR in the scenario 2

As it can be seen from Fig. 11. Packet delivery ratio decreases as mobility speed increases since link breakage can occur more frequently which causes high packet loss rate.

DSR shows higher Packet delivery ratio in high density networks since it uses the most fresh and reliable routes when needed contrary to AODV that uses existing routes in routing tables.

Summing up the results, it can be concluded that, it can be noticed that DSR protocol performs better in small networks at any mobility speed and that AODV protocol gives his best results in networks with a relatively high number of traffic and high mobility speed and offers a better delay with high density networks. OLSR protocol shows a very low delay in both scenarios of simulation and that mobility does not affect the density of traffic, but it increases with the network load. Also, OLSR protocol has a constant throughput in both cases of mobility speed since it's is a proactive protocol that manages the consistent routing tables offering a coherent delay and this demonstrates its overall superiority. It should be noted that if the network grows, OLSR routing tables can become too large and this causes network congestion and leads to a degradation of the performance.

In general, reactive protocols are more efficient than proactive protocols in terms of packet delivery rate (PDR), End-to- End delay (Delay) and throughput.

TABLE II: COMPARATIVE TABLE OF ROUTING PROTOCOLS

Routing Protocol	Conclusions
DSR	Very suitable for low density networks. Therefore, it would generate higher routing traffic in IPv6 environments.
OLSR	Very adequate to high broadband networks. The high routing traffic generated shows that OLSR is not suitable for low-density networks.
AODV	Suitable for low and medium density networks with low mobility speeds.
DSDV	Slow protocol since it uses a periodic and event-based update which causes excessive control in communication process.
ZRP	The value of the area radius determines its performance. This value should be small for better performance.
GRP	Reduces significantly the signalization (control packets) especially in large and dynamic networks

V. CONCLUSIONS

In this paper, the different classes of MANETs routing protocols have been reviewed considering two key parameters that influence their implementation: the density of the network and the nodes mobility rate. Thus, the design of a routing protocol for mobile ad hoc networks must consider all factors and physical limitations imposed by the environment to avoid the degradation of the system performance.

On the basis of the promising findings presented in this paper, we intend in our future research to work on the remaining issues and to concentrate on the adaptation of these routing protocols for an application in wireless sensor networks. Results will be presented in future papers.

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