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Flying Ad Hoc Networks (FANETs) in Emergency Applications: Evaluation of the Performances of Five Routing

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Abstract: The incising use of Unmanned Aerial Vehicles in all domains and especially for emergency and rescue situations, had push researchers to enhance their performances. When flying nodes work together, they create a Flying Ad Hoc network. Communication is one of the important keys of the good work of such infrastructure-less networks. In this article, the performances of five routing protocols, from three different categories, are evaluated in order to select the most efficient protocol for an emergency scenario. A routing protocol is the way nodes communicate between each other's and it can be simulated with the use of a mobility model, the way nodes move in the simulation area. The comparison includes two proactive, two reactive and one geography-based routing protocols and two mobility models are used. A discrete-event networks simulator is used and the evaluation includes three metrics; the packet delivery ratio, the throughput along with the end-to-end delay. Different tests were done for many scenarios to determine how the speed or the number of nodes or the packets transferred size affect the protocol's performances.

Keywords: *Emergency Applications, Flying Ad Hoc networks, Mobility Models, Routing Protocols, Unmanned Aerial Vehicles*

1. Introduction

An Ad Hoc network can be presented as a temporary Local Area Network (LAN) that connect nodes with others without the need of base stations or access points [1]. Unlike traditional networks, Ad Hoc Networks are decentralized self-provided, and each node participates in the routing activity. The first Ad Hoc network system was the Packet Radio networks [2] that was created in 1973 by the Defense Advanced Research Projects Agency (DARPA). This project was initiated by a military need of the United States department of defense, in order to provide communications in a mobile environment and to control and move traffic. Since that, Ad Hoc networks have evolved and diversified types raise, each determined by the nature of the nodes utilized. As an example, the well-known Mobile Ad Hoc Network (MANET) with mobile devices, Vehicular Ad Hoc Network (VANET) with intelligent transport systems (ITSs), Wireless Mesh Network (WMN) with cellphones, computers, hubs, or radios and Flying Ad Hoc Networks (FANET) with Unmanned Aerial Vehicles (UAVs). Ad Hoc networks can be used in numerous applications like monitoring, agriculture, surveillance, emergency and various military applications. The biggest concerns with such networks are both physical and logical security, routing, nodes low transfer speeds and bandwidth limitation.

This work is about FANETs, spontaneously formed networks composed by UAVs, aircraft with no pilot or passenger onboard that are piloted autonomously or by a remote control. Their main characteristics are the high mobility of the flying nodes, the frequent topology changes, and the scarce of resources [3]. These networks can especially be used in research and rescue operations, in areas where there is no per-installed communication infrastructure. Based on the Global UAV Market Report of the year 2022 [4], the use of Unmanned Aerial Vehicles has increased excessively during the ten last years , and still is expected to increase, especially in the civilian applications (like for photography and videography, mapping, delivery, or data transmission). A special case is their use during the Covid-19 outbreak, during which millions of people died and is still a deadly and worldwide spread virus [5].UAVs have been used in many ways to limit the propagation of the virus in many developed countries [6]. These technologies proved their efficiency in the fight against pandemics and the limitation of their propagation.

In such emergency situations, it is challenging to ensure that the routing protocol can determine the most efficient routes. In addition, it is also important to ensure that these routing protocols are reliable with the high mobility of the nodes. In networks simulation, mobility models are employed to test protocols in different situations, they represent the movement of the nodes. These models try, as much as possible, to mimic the real movement of the nodes over the time, their position, acceleration and velocity [7]. For each application, different mobility models can be applied. For FANETs, different mobility models can be used and are presented in two large categories: traditional models and recent developed mobility models. The traditional mobility

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models can be divided into six main sections: random, time-dependent, space-dependent, path-planned, connectivity-based and coverage-based [8]. In this work, five routing protocols are compared, two proactive protocols (Optimized Link State Routing (OLSR) and Destination-Sequenced Distance Vector (DSDV)), two reactive protocols (Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR)) and a Geographic/location-based one (Greedy Perimeter Stateless Routing (GPSR)). They are tested in the case of two mobility models and compared in terms of packets lost, the rates received, and the throughput.

The reminder of the rest of this paper is as follow. In the first part, the routing protocols and the mobility models are reviewed. In the second part, related works are presented and the third part describes the proposed work. In the final part, the protocols are compared via the simulation.

2. Mobility Models and Routing Protocols Review

An Ad Hoc Network, a mobility model is an efficient and realistic way to represent the movement of the nodes. Researchers used it mainly to analyze and test different systems that they can propose.

A first part of the section reviews three traditional mobility models suitable for FANETs nodes movement as well as some of the latest models developed.

2.1. Mobility Models

The predecessors of all the mobility models are the random mobility models [9] where there no relation between the direction, the speed of a node at time t with their past values at time t-1. Especially, the model often used for Ad Hoc Networks is the Random Waypoint Model (RWP) [10]; each node, at each time interval, selects a random destination in its predetermined zone of movement, a random speed between zero and a selected maximum speed and then moves. When it reaches its next destination, the node pauses and selects another speed and direction and so on until the time ends.

The second traditional mobility model, especially designed for UAVs, is the Paparazzi mobility model (PPRZM) [11]. It is a path-planned model where each node follows a predefined trajectory and is not at all a random movement. In fact, a node can have on of the five following types of movements: Staying at (hover over a fixed, a predefined position), Way-point (the node moves towards a destination by using direct, straight path), Eight (its trajectory has the shape of the number eight), Scan (defines two point to scan an area via round trips), and Oval (shifts round trip among 2 points and turn around when passing both points).

The last traditional model presented is the Gauss-Markov Mobility Model [12] which is based on the Gauss-Markov process [13], a stochastic process that satisfy both the Gaussian and Markov processes. With the model, initially, each UAV have a specific direction and speed. After, for each period of time, the direction and the speed of the nodes are refreshed based on the last positions using Gaussian equations. This model is more detailed in next.

During the last few years, new mobility models were developed especially to mimic, as much as possible, the movement of the flying nodes. Examples of these models are the Alpha Based Mobility Model (ABM), the Particle Swarm Mobility Model (PSMM), and the Semi Random Circular (SRC).

In the Alpha Based Mobility Model (ABM) [14], the energy, the connectivity, and the coverage are taken into account in the choice of a node's next move. In this model, each node gathers information from its neighbors to create a neighbor table that is updated after each t. Each node calculates a follow-ship weight (α) based on three parameters: the hop count, the number of neighbors, and the node's energy. This α represents the node's willingness to be followed by nearby nodes and varies from 1 to 10 (least to most recommended UAV to be followed).

The Particle Swarm Mobility Model (PSSM) [15] is derived for the principal of the Particle Swarm Optimization (PSO) [16]. The movement of nodes has both temporal and spatial relations, in fact, a node keeps into account a safe distance to other nodes in order to avoid collisions, and this distance is determined based on the assumption that information are shared in the network. PSSM has two stages. In the first step of Generation of velocities and waypoints, the trajectory of a node is assumed to be sequence of waypoints at discrete times. The next waypoint at time t depends on the velocity at time $t - 1$ and the location of the center at time $t - 1$. In the second step of Collision-free adjustments, the nodes which are located not at a safe distance are identified and their position is adjusted, keeping changes in the spatial-temporal properties as minim as possible.

In contradiction with all other mobility models, the UAVs in the Semi Random Circular mobility model (SRC) [17] have autonomous navigation. The model has both random and non-random properties, the nodes rotate anti-clockwise around the center of a circular area with a common constant altitude. In fact, a node moves in a circular motion and when it reaches a destination point, it randomly chooses another circle, with the same center, and moves towards another destination point. This model is mainly used when FANETs are used for surveillance: suitable when flying nodes turn around a specific area to capture different types of information.

2.2. Routing Protocols:

This second part of the section reviews the routing strategies that can be employed in flying nodes networks.

In networks, routing can be defined as the process of path selection [18]. Plenty of routing protocols are available in the research literature for Flying Ad Hoc networks however in the following, few protocols are explored. These protocols deal as much as possible the flying nodes special characteristics.

In general, routing protocols are categorized into the six following main categories: static, proactive, reactive, hybrid, geographic, and hierarchical [19]. First, the static protocols are used when the network's topology is fixed and cannot change during the flight, and the number of routes created is limited. Each UAV has a static routing table configured before the beginning of the mission that is never changed during its movement. Their main drawback is that these protocols are not fault tolerant. As an example Data Centric Routing (DCR) Protocol, used to retrieve a specific data from several nodes. The priority here is given to the type of information needed rather than the identity of the sources. DCR is mainly used for Wireless Sensor Networks [20].

Second, in Proactive Routing Protocols, a node periodically maintains one or more tables that indicates the network's whole topology. Because lot of data is preserved, the overhead in proactive routing is elevated, so they are not suitable for highly dynamic or large UAV networks. In Destination-Sequenced Distance Vector (DSDV) [21] protocol, every node have data about all the other network's nodes stored in a table and this routing table is updated periodically. Also, a sequence number is affected to each flying node, the node with the stronger sequence number is more efficient and moves faster. DSDV is a simple protocol but resists to network congestion when nodes change their positions. In Optimized Link State Routing (OLSR) [22] protocol, full information about neighboring nodes is stored and periodically updated by nodes. So, when a communication is required, the protocol quickly determines the route by applying Dijkstra (the shortest path algorithm) [23]. OLSR uses a flooding strategy to shave data and is the most used routing protocol in all types of Ad Hoc networks where nodes need to share data they collect within the network.

Third, Reactive Routing Protocols or on-demand routing protocols that determine routes only when requested. Compared with proactive protocols, these protocols are more dynamic and efficient, however they produce more latency because of the way route are search. The Dynamic Source Routing (DSR) [24] is a wireless multi-hop routing protocol where a source node only tries to find a path to a certain destination to share data with it. A routing table is used by some nodes and only the nodes used in the different paths periodically maintains it. The protocol is composed by two main steps: route discovery and the route maintenance. DSR allows the flying network to be self-organized and self-configured. Ad Hoc On-Demand Distance Vector (AODV) [25] is also a reactive routing protocol and in the same way creates routes on demand. The main features of AODV are the efficiency of the bandwidth use, the loop free routing, and the response to changes in topology. AODV is composed by three phases: Route discovery, Packet Transmitting, and Route Maintaining. When a source node wants to communicate with another node, it initiates a "route discovery" operation in order to localize the destination and then forwards the packet via a specified route during the "packet transmission" step. The final step is used to recover from a link failure.

Fourth, the hybrid routing protocols are a combination of proactive and reactive routing protocols. Hybrid protocols are suitable for large networks, they are based on the principle of zones, where a proactive protocol operates inside the zone and a reactive routing protocol is used for the communication between different zones. Zone Routing Protocol (ZRP) [26] is the most popular and known hybrid routing protocol. The network is divided into zones or clusters, the inside routing (intra-zone) uses a proactive routing technique to maintain the routes between the nodes within the same zone and the between zones routing (inter-zone) uses a reactive routing to connect a source and a destination located in different zones.

The fifth category is the Geographic or Position Based Routing Protocols. For such protocols, the nodes know their physical position via a GPS system or other type of positioning system. No route discovery process is requested when a source wants to communicate with a destination. In Geographical Routing Protocol (GRP) [27], a position-based and hybrid routing protocol, two routing strategies are used, the greedy forwarding where data is sent to the nearest node, in terms of position, to the destination, and the face-2 routing that is based on the planner graph traversal [28]. Greedy Perimeter Stateless Routing (GPSR) [29] is a protocol initially developed for a swarm of searching flying nodes. In GPSR, the packets are sent to a geographic set of coordinates because every node is assumed to know its position. Nodes periodically advertise their geographic coordinates so every node could maintain a list f the positions of only the nodes it communicates with. This protocol mainly uses greedy forwarding technique, however in some zones that is not possible so protocol routs around the region's parameter. GPSR has proven its efficiency especially with networks where the topology changes frequently.

Finally, in the Hierarchical Routing Protocols, the nodes are grouped into clusters, in a hierarchical way, and for each cluster there is a cluster-head responsible of the communication with other clusters. As an example, the Mobility Prediction Clustering Algorithm (MPCA) [30] is based on the tree structure prediction algorithm and the link expiration time. The protocol determines the different clusters formation based on the nodes mobility.

3. Method Selection

In this section, a studied simulation method is presented. First, in order to test a routing protocol in Ad Hoc Networks, the choice of a mobility model is essential because it shapes the movements of the nodes.

The selection of the mobility models to employ is based on their availability and their possible implementation in the different simulation Software. In addition, in our studied emergency scenario, the nodes have to cover the maximum of the search area. For the following work, we selected two mobility models: the Random Waypoint and The Markov-Gauss mobility models.

Random Waypoint Mobility Model (RWP): Within this model, the nodes are free to move freely in the simulation area, their speed and direction are random and independent of the other nodes.

Gauss-Markov Mobility Model (GM): Within this model, every UAV has an initial direction and speed, at each interval of time, a new speed and direction are calculated using a tuning parameter α (this parameter expresses the randomness of the model and it value is between 0 and 1) [39]. The UAV actual movement is associated with its previous movement through three Gaussian equations [40].

Based in the equations of the Gauss-Markov mobility model, if $\alpha = 0$, the movement becomes memory-less (the next velocity and movement depends on the average velocity and direction offset). And if $\alpha = 1$, the movement of the nodes will lose all it random-nesses (the next velocity and direction are the same as those before).

Each of the routing protocols introduced before has its benefits and its drawbacks depending on the application and the parameters in use. The three first categories are the main employed in FANETs researches because they are generally easy to implement and they deal well with the characteristics of the flying nodes. In addition, the majority of the new routing algorithms are still under testing and development and the parameters of using them are not always easy to retrieve or implement. In addition, the software of simulation of such protocols are not available and free for all the research community. Nowadays, some protocols have been discarded from the area of flying wireless networks and some are still under improvement to feet as much as possible the unique design and challenge of these networks. In our work, considering the proposed scenario of emergency, five routing protocols are evaluated: AODV, OLSR, DSDV, GPSR and DSR. The selection of these routing protocols is done according to the goal of our emergency and rescue work that is to detect possible victims in a specific area. In fact, different protocols are already mainly in use in many wireless networking applications. We selected such routing protocols to evaluate, from two different categories and selected one from another category. In addition, as for the mobility models, the free available software do not to support and give the access to the simulation of all the available protocols in the literature especially the new ones.

With Ad Hoc On-Demand Distance Vector (AODV), a reactive protocol, as soon as a source node requests a route, the protocol builds it and the routes created are maintained as long as the different sources require them. Optimized Link State Routing (OLSR), a proactive and table-driven protocol based on the flooding process that provides optimal routes. Destination-Sequenced Distance Vector (DSDV) is a proactive routing protocol where every node of the network has a table and regularly sends updates to advertise its location. Dynamic Source Routing (DSR), an on-demand protocol that allows the network to be autonomous and self-organized. Greedy Perimeter Stateless Routing (GPSR) is a geographic location based routing protocol. In case a node wants to transfer a packet to another node, it mentions the destination IP address.

Table 1 gives the main the strengths and weakness of the five protocols.

Table 1. Advantages and disadvantages of the selected routing protocols.

Protocol	**Advantages**	**Disadvantages**
AODV	• Quick response to changes in topology • Support Unicast and Multicast communications • Efficient protocol because of its on demand nature • Normal Overhead • Reduced delay in path creation	• Higher throughput • Higher end-to-end delay • Higher consumption of processing resources • Increased congestion • Higher power consumption
DSDV	• Suitable for small networks • Flat routing protocol	• Slower packet delivery • Requires regular update of routing tables • Not suitable for dynamic large networks
DSR	• Efficient protocol because of routes created when needed • Reduced overhead • Reduced collision because of use of	• Higher delay • Rapid performance degradation when increased mobility • Higher overhead • Route maintenance

	intermediate nodes	does not repair a link failure
GPSR	• Minimized overhead • Scalability to dense wireless networks • Benefits from the use of a positioning system • Low volume of messages	• Higher time between the time of calculation and the send • Can lead to wrong packet forwarding decisions • Requires the use of a positioning system on each node
OLSR	• Constant overhead despite the increase of route created • Less average end-to-end delay • Flat routing protocol	• Larger amount of bandwidth consumed • Higher overhead • Higher consumption of power and network resources

4. Evaluation and Tests

4.1. Environment of Simulation and Performance Metrics:

The performances of the different routing protocols are evaluated are studied via the simulator Network Simulator NS3 [46]. It is a discrete-event test system for the most part utilized for networks simulation and has various extensions that help give the most effective simulation results for different types of networks. The evaluation includes the end-to-end delay, average throughput, and the packet delivery ratio. These three evaluation parameters are helpful in the indication of how the protocol feet the special nature of FANETs. Moreover, two nodes mobility models are tested: the RW and GM mobility models.

The performances of the proposed network being evaluated are, first the throughput, which is the sum of all the received packets in all destinations, divided by the duration time of the simulation and is generally expressed in bytes per second (bps). Second the packet delivery ratio, which is the ratio of the successfully received packets by destination to the total number of the data packet sent. Third, the network's average end-to-end delay which is the average of all the packets end-to-end delays, the time between a packet quits the source and the time it reaches the destination. It is the total time of packet transfer. Higher the throughput, the packet delivery ratio and lower is the end-to-end delay, better the protocol is.

For the simulation, two parts along with two mobility models are done. For both RWP and GM the simulation overall time selected is 1200 seconds and the evaluation was done for (that is to see and determine how the nodes number, their speed and the size of the packets transferred affect each protocol's performances):

- Two different network's topologies: 25 and 50;
- Two UAV's speed: 15 m/s and 25 m/s.
- Two size of packets: 512 and 1024 bytes.

4.2. RWP:

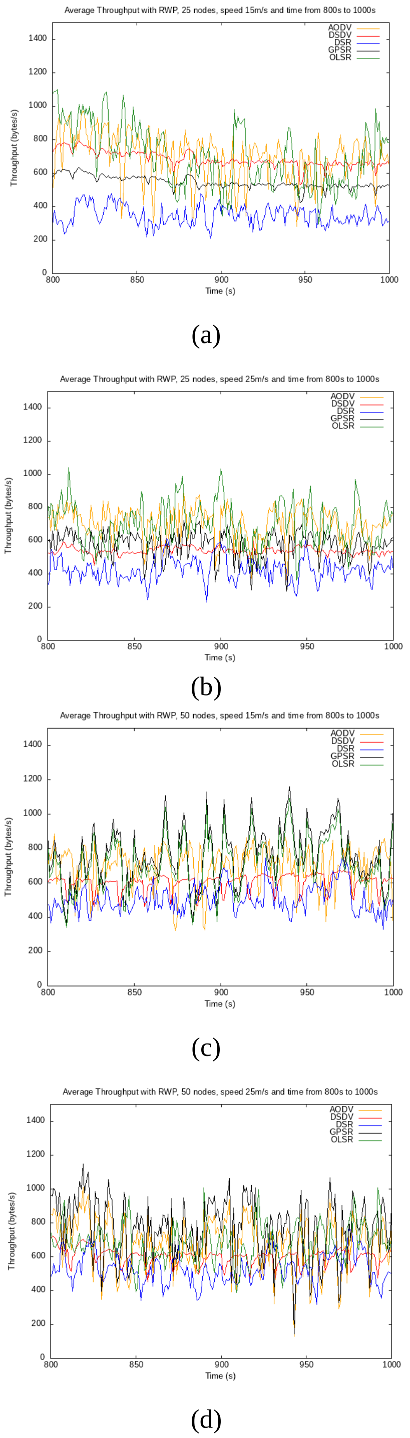
In this first part of the simulation, the RWP is used, the nodes have random movement in the chosen area of simulation and for each scenario, and the movement is different. We select an area of 500*500*100 (m) with no pause time. All the simulation parameters are detailed in the following table, they are selected based on the average real parameters registered for different UAVs.

Table 2. RWP simulation parameters.

Parameter	**Value**
Area of simulation	500*500*100 (m)
Overall simulation time	1200 (s)
Number of nodes	25, 50
UAV Speed	15, 25 (m/s)
Data transfer rate	1 (Mbps)
Size of packets	512, 1024 (bytes)
Pause time	0 s
Mobility Model	RWP

4.2.1. Throughput

Figure 1 shows results of the throughput considering packet size of 512 bytes, precisely the average throughput of all the nodes at each moment in the simulation. The average throughput is represented in two cases 25 and 50 nodes and for each case, two speeds are considered (15m/s and 25m/s). Moreover, the results presented are from the simulation time 800s to 1000s in order to see the differences. Average throughput with 25 nodes, speed of 15m/s (a), speed of 25m/s (b), 50 nodes, speed of 15m/s (c) and speed of 25 m/s (d) are shown.



(a)

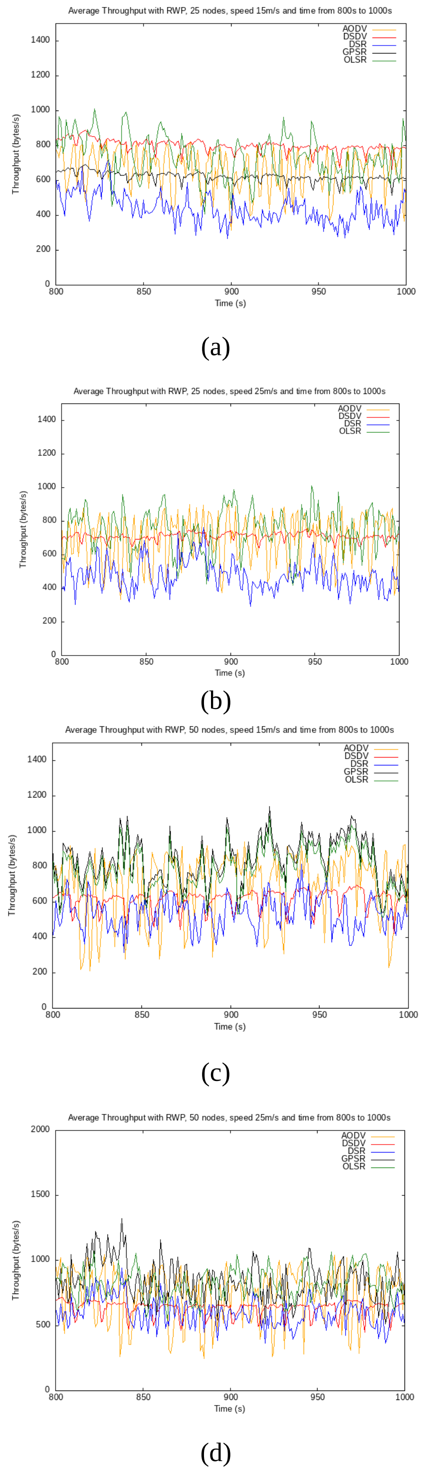
(b)

(c)

(d)

Fig. 1. Average throughput in bytes/s with RWP, simulation time from 800s to 1000s and packet size 512 bytes (a) 25 nodes, 15m/s (b) 25 nodes, 25m/s (c) 50 nodes, 15m/s (d) 50 nodes, 25m/s.

Figure 2 shows the same throughput results for packets size 1024 bytes and table 3 displays the calculated average throughput for all nodes during all the 1200s of simulation.



(a)

(b)

(c)

(d)

Fig. 2. Average throughput in bytes/s with RWP, simulation time from 800s to 1000s and packet size 1024 bytes (a) 25 nodes, 15m/s (b) 25 nodes, 25m/s (c) 50 nodes, 15m/s (d) 50 nodes, 25m/s.

Table 3. Throughput with RWP.

Packet Size	**512**				**1024**			
Nodes nbr	**25**		**50**		**25**		**50**	
Speed	**15**	**25**	**15**	**25**	**15**	**25**	**15**	**25**

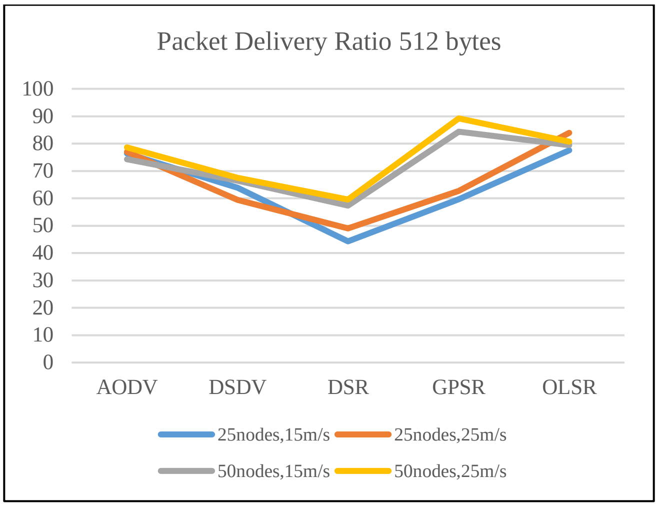
AODV	764,2	769,1	742,3	785,5	729,1	761,1	765,3	845,5
DSDV	638,9	594,4	664,8	675,3	877,7	777,2	679,6	706,2
DSR	442,9	490,1	573,4	595,6	543,5	546,7	590,6	699,4
GPSR	596,5	627,6	843,4	891,9	683,4	697,1	907,5	985,1
OLSR	775,3	839,3	794,2	806,7	852,5	854,3	863,9	912,8

As shown in figures above and the table, the average throughput of both protocols AODV and OLSR is good in all configurations, DSR has the lowest throughput and when the node density or the UAV speed increases GPRS outperforms all other protocols. These results can be explicated by the fact that in DSR, the use of the RouteRequest and RouteReply packets consume time when a source node wants to transfer a packet. With OLSR, all the nodes already know the routes to each-other and with GPRS, the nodes know the geographic position of the receiver nodes so the packet transfer is more rapid. With AODV, the routes created are maintained, and in DSDV, the use of the Bellman–Ford algorithm, leads to averagely good throughput.

4.2.2. Packet Delivery Ratio

First, the total number of packets sent in the network is calculated based on the transfer rate, the packet size and the overall simulation time. For packets of 512 bytes, the total number of packets sent are: 2,343,750 and for 1024 bytes 1,171,875 packets were sent. Second, the sum of the packets received need to be calculated. In figure 3, the graphs of PDR for all simulation scenarios are presented.

As shown in the graphs, for all cases DSR has the lowest packet delivery ratio, after comes the protocol DSDV. The other routing protocols are averagely well, especially OLSR and GPSR presents similar and higher performances when the node density increases or the UAV speed increases. The results of PDR are in relation with the results of throughput because for all the routing protocols, the PDR is calculated based on the number of packet sent (that is the constant) and the number of packet received (that depends on the mechanism of route selection used by each protocol).



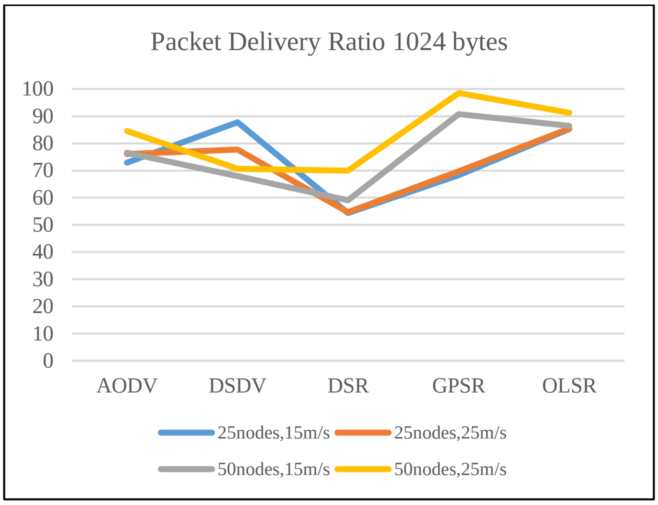
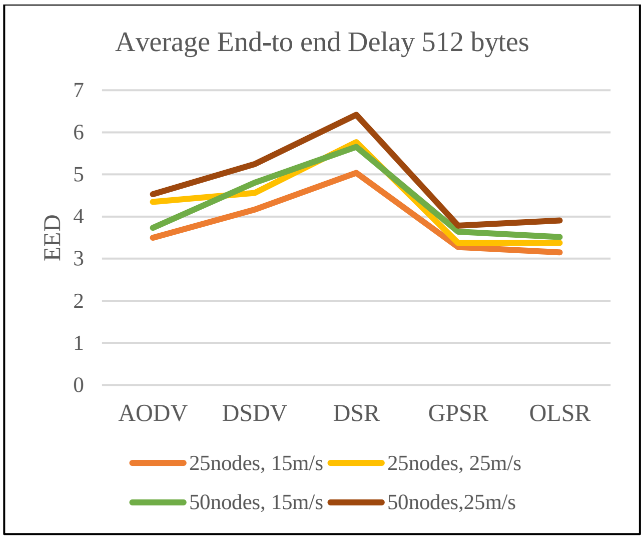


Fig. 3. Packet Delivery Ratio in %.

4.2.3. End to end delay

In figure 4, for both packets sizes, the average end-to-end delay of network with 25 nodes, speed of 15m/s (a), speed of 25m/s (b), 50 nodes, speed of 15m/s (c) and speed of 25 m/s (d) are shown. In table 4, the average end-to-end delay for all nodes during all the 1200s of simulation.



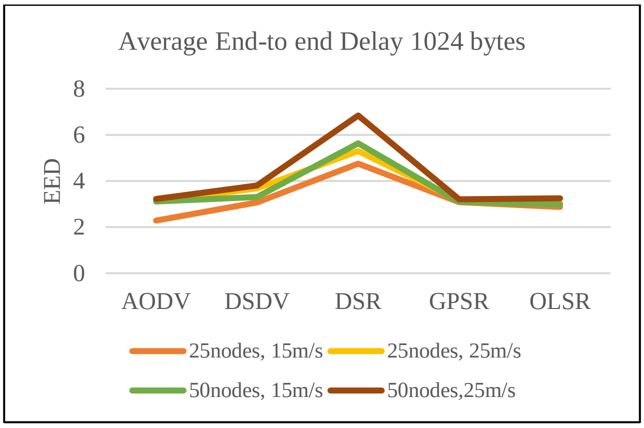


Fig.4. Average EED

Table 4. EED with RWP.

Packet Size	**512**				**1024**			
Nodes nbr	**25**		**50**		**25**		**50**	
Speed	**15**	**25**	**15**	**25**	**15**	**25**	**15**	**25**
AODV	3,49	4,34	3,73	4,53	2,28	3,117	3,12	3,21
DSDV	4,16	4,56	4,80	5,24	3,07	3,681	3,31	3,81
DSR	5,07	5,76	5,65	6,41	4,75	5,298	5,63	6,84
GPSR	3,27	3,37	3,64	3,78	3,08	3,159	3,09	3,21
OLSR	3,15	3,37	3,51	3,90	2,87	3,054	2,98	3,25

It can be seen through the results that for DSR, the reactive protocol, the route discovery before each packet transfer, leads to higher end-to-end delay in comparison with other protocols. The mechanism of hop-by-hop used in AODV leads to good performances. For the proactive protocols, the whole topology is maintained by every node so the packets are routed more rapidly which leads to lower end-to-end delay, especially OLSR that gives the best results. For the position-based protocol, the use of geographic coordinates when transferring a packet is more effective in relatively dense networks with high speeds of the nodes.

4.3. Gauss-Markov

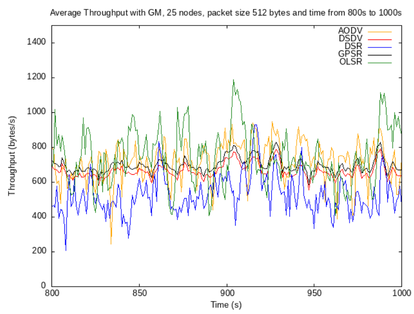
For the second part of the simulation, the main parameters used for the Gauss-Markov mobility model are shown in the following table.

Table 5. GM simulation parameters.

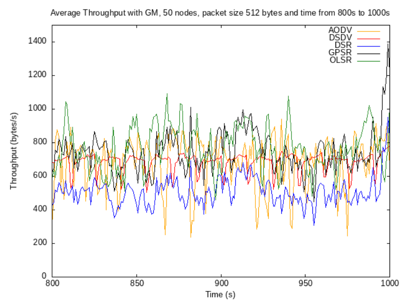
Parameter	**Value**
Overall time	1200 (s)
Number of nodes	25, 50
Data transfer rate	1 (Mbps)
Size of packer	512, 1024 (bytes)
Bounds	X [0 500] Y [0 500] Z [0 100]
Time Step (s)	0,9
A	0,7
Mean Velocity	[15 25]
Mean Direction	[0 2π]

4.3.1. Throughput

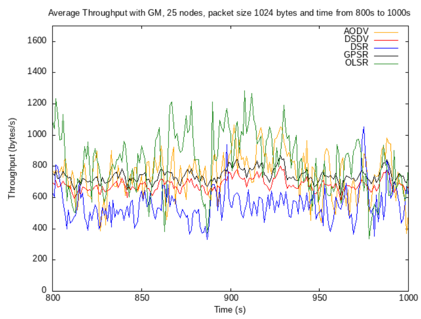
In figure 5, for network of 25 nodes, the throughput of network with packet size 512 bytes (a), 1024 bytes (b), 50 nodes, with packet size 512 bytes (c), 1024 bytes (d) are shown. In table 6, the average end-to-end delay for the scenarios of 25 nodes and 50 nodes is show, for both packet sizes 512 and 1024 bytes. As before, the results are shown for simulation time from 800s to 1000s.



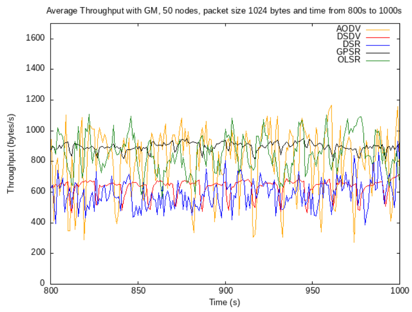
(a)



(b)



(c)



(d)

Fig. 5. Average throughput in bytes/s with GM, simulation time from 800s to 1000s, (a) 25 nodes, packet size 512 bytes (b) 50 nodes, packet size 512 bytes (c) 25 nodes, packet size 1024 bytes (d) 50 nodes, packet size 1024 bytes.

The average throughput for the five routing protocols are similar to those obtained before. In fact, for all simulated configurations, the least important throughput is given by DSR, after comes DSDV and then AODV. Both OLSR and GPRS give interesting results in terms of average throughput with the Gauss-Markov mobility model, for both 25 and 50 nodes and 512 and 1024 bytes packet's size.

Table 6. Throughput with GM.

Number of nodes		**25**		**50**	
Protocol	**Bytes**	**512**	**1024**	**512**	**1024**
AODV		349,520	475,019	333,267	448,494
DSDV		294,414	399,067	330,619	374,214
DSR		159,089	215,524	204,200	214,558
GPSR		329,372	460,278	452,423	613,693
OLSR		341,520	581,778	430,301	607,307

4.3.2. Packet Delivery Ratio

The PDR is calculated via the same technique used in the first part of the simulation, in figure 7, for network of 25 nodes, the packet delivery ratio in % for the different protocols and scenarios is shown.

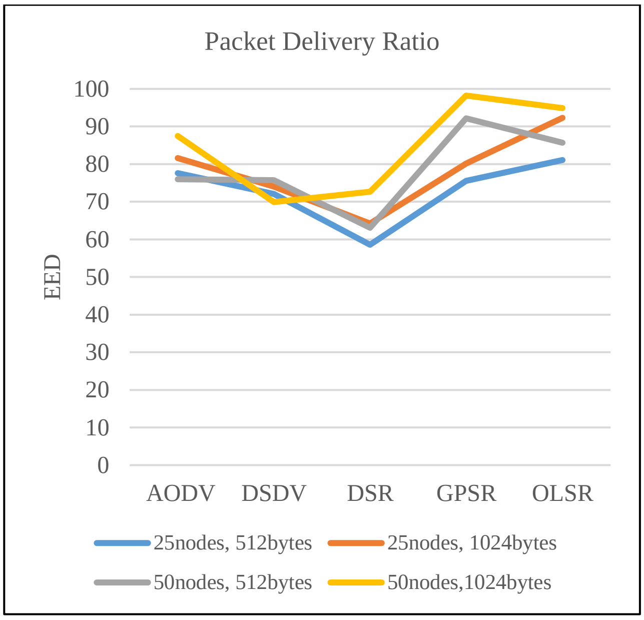


Fig. 6. Packet Delivery Ratio GM in %.

It can be seen that, when the node density is high and the packet size also, the majority of the five routing protocols presents higher packet delivery ratio. As expected, OLSR outperforms all other protocols but in the last configuration GPSR outperforms it. Because the PDR is calculated based on the number of packets received, the results obtained are in line with results of throughput for all five protocols.

4.3.3. End to End Delay

In figure 7, the average end-to-end delay for the scenarios of 25 nodes and 50 nodes is show, for both packet sizes 512 and 1024 bytes. In table 7, the average end-to-end delay with Gauss-Markov mobility models for all configurations.

Because of the nature of route discovery process used by the protocol, DSR has a high average end-to-end delay in whole scenarios. After DSR comes DSDV witch is a proactive routing protocol that uses a table where it stocks some information about the nodes. The use of sequence number in route selection does not help in having a low average end-to-end delay. The reactive protocol AODV has a competitive end-to-end delay when node density and node speed are averagely low. With OLSR, the advance availability of routes leads to less time to transmit the packet to the receiver node. The results have also proven that the technique of positioning used in the geography-based protocol helps in maintaining a low end-to-end delay.

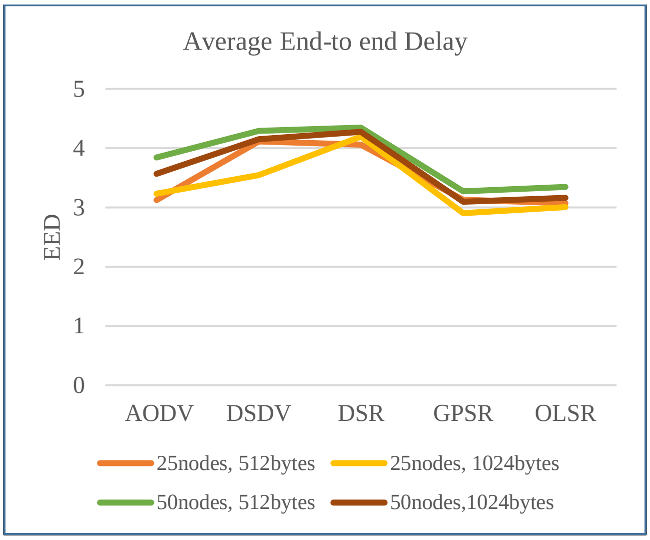


Fig.7. Average EED with GM

Table 7. EED with GM.

Number of nodes		**25**		**50**	
Protocol	**Bytes**	**512**	**1024**	**512**	**1024**
AODV		3,1217	3,2320	3,8427	3,5673
DSDV		4,1141	3,5443	4,2945	4,1502
DSR		4,0596	4,1945	4,3468	4,2763
GPSR		3,1276	2,9035	3,2720	3,0957
OLSR		3,0715	3,0043	3,3457	3,1642

4.4. Discussion:

After running all the different scripts in NS3, which each corresponds to a network's configuration, collecting, and analyzing the obtained results we came to the conclusion that the performances of each the protocols is quite the same for all considered configurations (i.e. mobility model, number and speed of nodes, exchanged packet size). In the opposite, the way a routing protocol works to find and select paths have a big impact on the network performances. OLSR, the proactive protocol, where routes are determined before the information exchange, provides the better performances. The on-demand routing protocols, where routes are determined when needed, presents average results, and precisely AODV is superior than DSR. Finally, with the geography-based protocol all the nodes geographic positions are known. The protocol deals well with networks with important number of nodes and where UAVs speed is greater. It can also be noted that the most stable of the five protocols are AODV, OLSR and GPSR.

After all the distinct analyzes, we came to the conclusion that. In an emergency situation, where collecting information about possible victims in less time is really important and where the number of nodes used depends on the available resources. And where the average UAVs speed is less low in, in order to well analyze all the search zone, the comparison is mainly based on the end-to-end delay, the time it takes a packet to be transferred from an emitter to a receiver. We recommend the use of OLSR as routing protocol.

5. Conclusion

For the last decades, technologies were developed in different domains. In wireless communications, specifically, Unmanned Aerial Vehicles were created, small pilot-less aircrafts that can be used in a variety of scenarios. Systems based on that technology represent a major part of the aviation future. As an example, Flying Ad Hoc networks, infrastructure-less networks composed by UAVs and that are employed in several civil applications (rescue, photography, delivery, agriculture …). That type of flying network have a major issue that consists on the frequent topology changes, caused by the high movement of nodes. To minimize such issue, a suitable routing protocol must be selected, the paths from where packets are transferred between the nodes. To sum up everything that has been stated in that work, five routing protocols were tested based on the average throughput, the packet delivery ratio and the average end-to-end delay. (Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR) two proactive protocols, Ad Hoc On-Demand Distance Vector (AODV) along with Destination-Sequenced Distance Vector (DSDV) two reactive protocols and Greedy Perimeter Stateless Routing (GPSR) a geography-based routing protocol). And because a routing protocol cannot be evaluated without a mobility model, the Random Waypoint and the Gauss-Markov mobility models were chosen. Moreover, three parameters were changed to determine how they affect the network's overall performances. Those parameters are the density of nodes, the speed of the flying nodes and the size of the packet transferred in the network. The results conclusion is that both protocols OLSR and GPSR are the most suitable protocols for our emergency situation. Nevertheless, in case the number of the nodes or their speed increases the position-based routing protocol is better to use. Future works can be the extension of existing routing protocols or the development of new routing protocols unique to the special flying nodes movement.

Author contributions

Chaibi Loubna: Conceptualization, Methodology, Simulation, Writing-Original draft preparation**,** Final Manuscript Writing **Sebgui Marouane:** Reviewing, Editing, Validation, **Bah Slimane:** Reviewing, Editing, Validation.

Conflicts of interest

The authors declare no conflicts of interest.

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