Performance Analysis of Routing Protocol for Ad Hoc UAV Network

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ABSTRACT

This paper provides an analysis of the performance of routing protocols in the paradigm of a FANET network. The protocols studied, AODV, OLSR and DSDV, were created based on the paradigm of MANET networks. Therefore, it becames necessary to verify the viability of the protocols in a FANET network. They are tested in several scenarios, where some important parameters are changed. In the final, it is concluded that proactive protocols have better performance on networks with high dynamic topology.

CCS CONCEPTS

• **Networks → Protocol testing and verification**; **Routing protocols**; **Network simulations**; *Network protocol design*; Network mobility;

KEYWORDS

FANET, Routing, UAV, AODV, OLSR, DSDV

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1 INTRODUCTION

Recently, the use of the Unmanned Air Vehicle (UAV), popularly known as Drones, has rapidly grown. Whether in natural emergencies and disasters, in military uses or in monitoring a specific area, such as a border between countries. This growth is due to rapid technological advances. Those allowed the production of UAVs that can travel without direct control of an individual [1][2][4][8].

The mobility and the drones management are software-based, facilitating the installation and scalability of multiple UAV systems. Each UAV can be connected directly to a ground base or to a satellite. This can be through, for example, 5G technology. However, this approach is not scalable due to some issues: first, to the cost and hardware complexity required to maintain this connection; to physical limitations such as the weight that the UAV bears - network equipment can carry considerable weight; or to the communication reliability, because the link of this connection is subject to environmental conditions, whether climatic or the terrain structure, or to the lack of coverage of a certain area covered by the UAV [1][2][4][8].

The dependence on infrastructure for the communication of a system of multiple UAVs is a challenge. An alternative to solve the difficulties presented above is the creation of an Ad hoc network between the UAVs, called Flying Ad hoc Network (FANET). The data can travel from one UAV to another until it reaches the network edge. The edge is a specific UAV, which is connected at that specific time to the central - the sink.

There are several studies on inter-node communication in an Ad hoc network. These have led to the creation of famous routing protocols such as Adhoc On-Demand Distance Vector (AODV), OLSR (Optimized Link State Routing) and DSDV (Destination Squenced Distance Vector). These protocols were designed to Mobile Ad hoc Network (MANET). MANET is a network similar to FANET with significant differences:

(1) **Mobility:** MANET node has a low or even zero mobility, while the drones in a FANET network move constantly.
(2) **Topology Changes:** The changes in the topology of a MANET network is slow and gradual, the opposite to FANET.
(3) **Radio propagation:** While the nodes in a MANET network lie close to the ground, the drones in a FANET network are at considerable height modeling the shape of the radius propagation.
(4) **Density of nodes in the network (# nodes / monitored area):** The density of nodes in the two networks can be considered low because the tendency is to allocate a minimum number of nodes to try to encompass the monitored area. Despite that, FANET tends to have a lower density due to constant movement and to the larger area that it can be monitored.

Given these differences between MANET and FANET, the protocols cited above may not be feasible in the FANET's context. AODV, OLSR and DSDV were proposed for MANET and need to be tested in the dynamic scenario of a Multi-UAV system. A system of multiple UAVs, in this research, aim to collect data - images, videos or sensor data - that must be transmitted to a central office. There the information will be properly processed as needed.The test will verify the viability of routing protocols in FANET or if it is necessary to search for new solutions. For that reason, the focus of this study is to analyze the performance of AODV, OLSR and DSDV protocols

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in different topologies and scenarios of a FANET network, using the ns-3 simulator

The paper is organized as follows: In Section 2, we explain, briefly, the protocols that are analyzed. Some papers have already performed an analysis on the area or more specifically these protocols. These works are discussed in Section 3. The simulation and the results are explained in Sections 4 and 5 respectively. The paper is completed in Section 6 where conclusions are described.

2 ROUTING PROTOCOLS FOR AD HOC NETWORKS

This work intends to study three protocols already mentioned: AODV, OLSR and DSDV. The purpose of this section is to briefly introduce them.

2.1 AODV (Ad-hoc On-Demand Distance Vector)

Ad hoc On-Demand Distance Vector is a routing protocol created for wireless communications. It allows the discovery of routes to nodes in an ad hoc network. It has reactive behavior because its route acquisition is exclusively on-demand. That is, routes are created and maintained only when necessary. If the link is not active, does not require the route storage. When a link loses its signal, the AODV warns the node to delete the route.

Its Destination Sequence Number (DSeqNum) mechanism prevents loops from occurring, making the protocol much more efficient. First of all, the DSeqNum is created by the packet source, indicating the location of creation. Each intermediate node increment the packet with the information of the next node of the sequence. Besides DSeqNum prevent loops, it also helps to store the routes on the nodes. When a node receives a DSeqNum that has an incompatible route or does not exist with its route table, it is updated. That is, the actual routing of a packet contributes to the discovery of the topology and consequently to other routing.

Another very important mechanism implemented by AODV is the RREQ (Route Request Packet). A broadcast packet for the whole network, with the objective of discovering the routes that the information should follow. The node that receives the RREQ may responds with Route Reply Packet (RREP). The RREP is answered only when the respective node has an active connection with the required destination. And through the information of the RREP, the source can acquire a route to the destination. In Figure 1, it can be seen an example of this. The source A wants to transmit a packet to destination F and, in this case, only B and D have an active link with F, so there is presence of RREP.

2.2 OLSR (Optimized Link State Routing)

Optimized Link State Routing is a proactive routing protocol for adhoc networks. It is considered proactive because the route is always available at the time it is needed. This is due to the regularly exchanging information about the network topology between the nodes. Each node is responsible for sending control packets to all other nodes (broadcast). These paradigm can generate an overhead on the network due to the large and continuous shipment of packages.

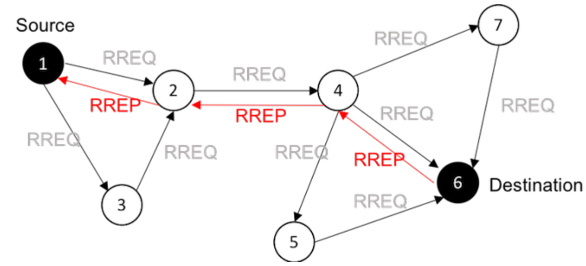

Figure 1: AODV route discovery.

Although the protocol presents problems with bandwidth requirements in an Ad hoc network, it can optimize communication by providing the shortest path using multipoint relay (MPR). MPR works by choosing a number of neighboring nodes that will help transmit control packets to the network, reducing the excess information on the network.

OLSR has four types of important control messages:

- Hello Messages: They are used to discover information about link status;
- Topology Control Messages (TC): They are used periodically to send information about the selection of the list of neighboring nodes, to reflect the MPR;
- Multiple Interface Declaration (MID): Message that is sent to the whole network by the MPRs. It is used to warn other nodes, that the respective node has several interfaces / addresses;
- Host and Network Association (HNA): is the same type of message as the TC, but with the difference that it has a validity. While a TC message needs to report a cancellation, the HNA does not have a set deadline.

Figure 2 is an exemplification of the MPR logic. Node six creates a TC message and sends it to four, five, and seven. Node 4 transmits TC (6) from node six and node 3 transmits TC (6.4) from node 4 and so on.

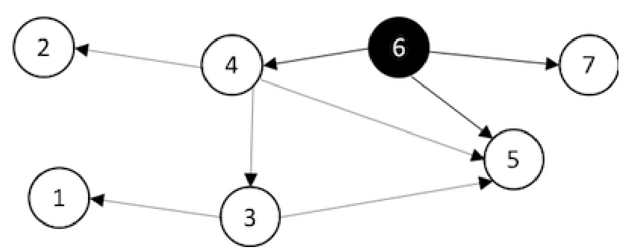

Figure 2: MPR logic example.

2.3 DSDV (Destination Sequenced Distance Vector)

Destination Sequenced Distance Vector protocol is a table-driven routing scheme for ad hoc mobile networks based on the Bellman-Ford algorithm. It is a proactive routing protocol, which proceeds the path to the destination immediately when requested. The path will always be in a table that is periodically updated due to the constant exchange of information between neighbors. Each entry in the routing table contains a sequence number that represent routing informations from other nodes [3].

When a link between two of the nodes is broken, a new information (table) is requested to the neighbors. If the a new sequence is found, the node must increment his routing table. If the node receives several tables, it must analyze which one has the best information, that is, the smallest path. Each row in the table has a sequential number and depending on the value, it can accept or reject the table. This mecanism is illustrated in Figure 3.

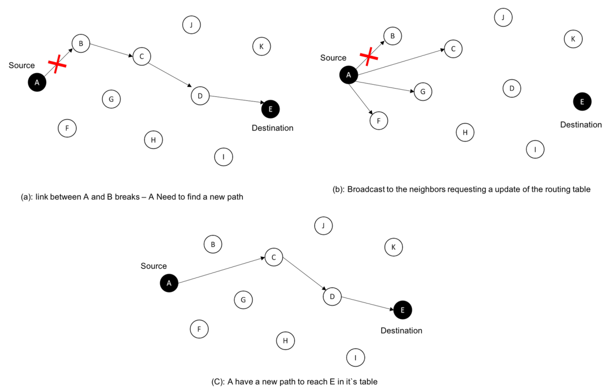

Figure 3: DSDV table updated logic.

3 RELATED WORK

The FANETs network paradigm is relatively new compared to other areas or with other Ad hoc networks such as MANETs networks. The literature on the subject has had a greater approach since 2013. In that year, Ilker Bekmezci [1] wrote an extensive and comprehensive review on the subject that focused on communication between UAVs - the possible architectures and protocols of communication. All of the proposed architectures have at least one drone connected to the base. It can be a hierarchical architecture, where there is one drone responsable to connecting the UAV network with the base. Another possibility is a cluster organization [5], where anyone from the swarm can connect to the base. On the protocols, Bekmezci presents a series of possibilities that are listed below.

While Bekmezci focused on the issue of communication, Khan [4] conducted extensive research on the FANET networks paradigm. He focus on application scenarios and possible architectures, comparing FANET with the other Ad hoc networks - Mobile Ad hoc Netork and Vehicle Ad hoc Network. There is discussed all communication protocol challenges for all physical, MAC, network and transport layers, including cross-layer. On the network layer, focus of this paper, Khan point out the same types of routing protocols as Bekmezci:

- **Static Routing Protocols:** Protocols based on the assumption that there are no changes in the network topology.
- **Proactive Routing Protocols:**Protocols that keep the network topology constantly updated for each node.
- **Reactive Routing Protocols:** Protocols that search and maintain the information of a route according to the communication demand.
- **Hybrid Routing Protocols:** Protocols that combine reactive and proactive practices.
- **Geographic/ Position Based Routing Protocols:** Protocols that are based on the fact that each node knows the geographical position of others.
- **Hierarchical Routing Protocols:** Scenario where nodes are divided into groups and each group has a leader. These one is connected with other leaders or with the base and which each node of the group is connected to it.

In addition to the points mentioned above, another huge issue is discussed. The mobility model of the drones in a FANET network. Each model, according to Khan and Zafar, [10] presents its application, as shown in Table 1.

Table 1: Applications of Mobility Models

Model	Aplication
Manhattan Grid	Ccomplex urban areas
Random WayPoint	Patrol Systems
Reference Point Group	Search and Rescue Missions
Gauss Markov	Relieable Network

The focus of this study is, as commented in Section 1, to analyze the performance of two types of protocols mentioned above: the proactive ones (OLSR and DSDV) and the reactive ones (AODV). There are two other papers that performed an analysis on the same protocols. Singh [7] performed simulations with the OLSR, DSDV and AODV protocols in a scenario with node numbers limited to 20, varying only their speed. The author concludes that the OLSR protocol is preferable to the other two. However, the analysis lacks some information, such as the size of the area covered by the drones, the number of data collection sites or which standard of 802.11 was used. In addition, the study is limited because the number of nodes is always the same. In that way, it is questionable the affirmation that one protocol is best.

Vasiliev [9], on the other hand, presents more information about its simulation of AODV, OLSR and Hybrid Wireless Mesh Protocol (HWMP) protocols. In it, the author varies the scenarios according to the size of the area covered (250 - 750 meters) and the number of nodes (10,15 and 20). This study aim to increase the number of scenarios studied by Vasiliev.

4 SIMULATION

The research is based on data collected from the simulation of an Ad hoc UAV network. This was accomplished using the ns-3 simulator. It allows the creation of the scenarios with the parameters in Table 2.

The simulation consists of a region defined by a parallelepiped, as in Figure 4. The box has base edges b and height of 20 meters. The UAV nodes move inside this box according to the mobility model chosen. In Addition, there is a central that stay fixed and communicate with the nodes that are within a maximum distance of communication. The nodes move according to a chosen mobility model. They communicate with each other in order to forward the data to the node connected to edge (sink).

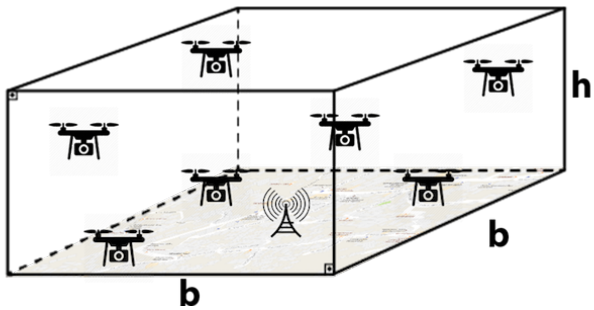

Figure 4: Reference box used in the simulation.

The main goal is to simulate the repetitive sending of images from the nodes to the sink. This aim to be similar to monitoring an area from time to time from a UAV unit. It takes a picture and sends it within a given interval of 10 seconds. However, as the main goal is to simulate the communication between nodes, the one that keeps sending photos and monitoring is considered fixed too. That is important to ensure that the sender is always at a significant distance from the sink. This distance forces the packet routing process through the ad hoc network. And the group of nodes, that are moving according a specific mobility, will have the work to find the path to transmit the packet.

The metrics used in the analysis of the communication between nodes-cloud and sink are:

- Throughput
- Delivery Rate
- Average Delay
- Average Jitter
- Mean Hops

Table 2: Simulation Input

Parameters	Value
Number of nodes	10,20,30,40, 45 and 50
Speed	5m/s and 10m/s
Mobility Models	1) Gauss Markov and 2) Random WayPoint
Frequence	5GHz
Band	54Mbps
Packet size	256bytes
Box arrest (b)	200, 300, 400, 500, 750 and 1000m
Box height (h)	20m
Link Layer	802.11n
Maximum Transmission Range	120m
Routing Protocol	AODV, OLSR and DSDV
Wifi Tx Power	20dbm
Transport Protocol	UDP
Simulation Time	400sec
Interval between Images	10sec

The parameters in Table 2 are manipulated to create the desirable scenarios. Table 3 shows the planned scenarios, which are varied according to number of nodes, box size and the nodes mobility. Each scenario are tested for each protocols studied: AODV, OLSR and DSDV and is analyzed according to the metrics presented.

About the main inputs, the mobility is split between Gauss Markov, to test the real reliability that this model can bring, and Random Way Point, for having an application similar to the idea of the project - to patrol a region. Manhattan Grid and Reference Point Group were disregarded as the project does not focus on an urban environment and does not consider drones organized in groups. Finally, the box size and the number of nodes are manipulated in order to test the influence of the network's density.

Finally, the simulation can be replicated by constructing the scenario with the parameters above in the ns-3 simulator.

Table 3: Simulation Scenarios

MOBILITY	VELOCITY	BOX (b)	NODES
Gauss Markov	5m/s	200, 300, 400, 500	10 a 40, 45 e 50
Gauss Markov	10m/s	200, 300, 400, 500	10 a 40, 45 e 50
Random WayPoint	5m/s	200, 300, 400, 500	10 a 40, 45 e 50
Random WayPoint	10m/s	200, 300, 400, 500	10 a 40, 45 e 50

5 RESULTS

First of all, the chosen transport protocol is UDP. It does not have the mechanism that aims to guarantee the receipt of the package. The protocol only sends it to the destination, and does not expect an answer or a confirmation. In opposition of TCP which objective is to guarantee the receipt, that keeps trying to send the packet until receive the OK from the receiver. Therefore, the subtractions below should be analyzed from the perspective that there is no retransmission.

In addition, there will be no concern about the overhead that control packets can generate. The overhead can be a issue comparing proative and reative protocols, but it will be shown below that reactive protocols, as AODV, are not the right solutions to FANET networks. Therefore, this will not be addressed by this study, although it is considered a very important parameter for choosing the routing protocol.

5.1 Delivery Rate

Results are illustrated in graphics that the X axis has two branches: number of nodes and the box size; and the Y axis has only one value. In the first case, Y is the Delivery Rate, which is illustrated in Figures 5, 6, 8 and 7. In general, for OLSR and DSDV, the delivery metric increases as the density of nodes grows, decreases as the speed grows and, consequently, when the box size grows, the delivery rate decreases.

The AODV Protocol, unfortunately, have a very poor perform and is infeasible for the proposed scenarios. This is consequence of reactive behavior of the protocol. It will only trace the packet route when it is needed and, once traced, it will be fixed. The lack of adaptability of the route against the network dynamic topology causes that, and the package rarely arrives at its destination.

5.1.1 Impact of Speed. Each protocol (OLSR and DSDV) has one specific behavior. DSDV performance is impacted by speed. At a lower speed, the protocol finds the route more easily and will try to always send the shortest route. When packet is sent, it will arrive at the destination only if the route is maintained. Otherwise, the packet will be lost and, since the transport protocol used is UDP, there are no checks and resends. Scenarios using 5m/s and 10m/s present results with expressive differences and can be explained with the same argument above. The nodes' speed is too high (10m/s) that the topology is very dynamic, and therefore, the route found can not be maintained.

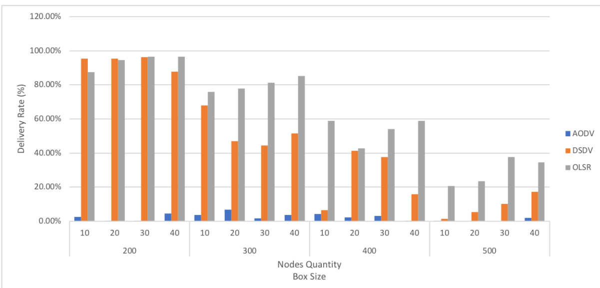

Figure 5: Delivery rate of each protocol in the scenario with Gauss Markov at 5m/s.

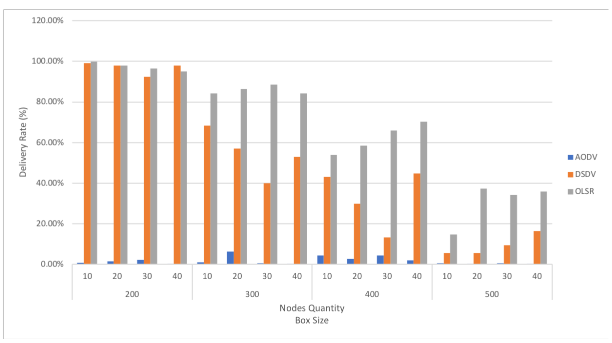

Figure 6: Delivery rate of each protocol in the scenario with Random WayPoint at 5m/s.

The nodes' speed also make a great influence on the OLSR performance, as can be seen comparing Figures 5 and 7. In those, it can be seen that speed increase causes the delivery rate to drop from a level of 80% to a 40-50% in a box with 300meters, for example. This consequence differs to the consequences generated by the speed increase in DSDV. The first one uses its neighbors, through the multipoint relay (MPR), which was discussed in Section 2.2, to find the best path. OLSR search the route that is mapped according to neighbor information. When sending the packet, the route can be changed according to the new information that the intermediate nodes receive.

5.1.2 Impact of Density. If the increase in speed generates a greater loss of packets, the decrease network density also affects the rate of loss. It can be noticed that both protocols, DSDV and OLSR, have

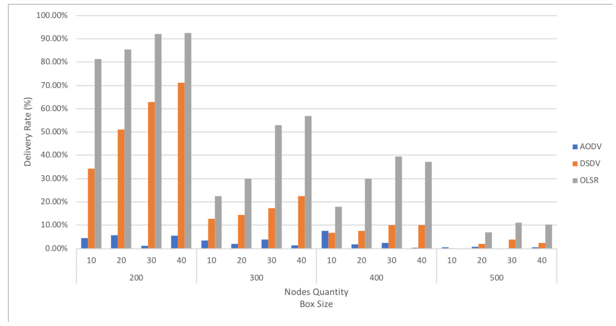

Figure 7: Delivery rate of each protocol in the scenario with Gauss Markov at 10m/s.

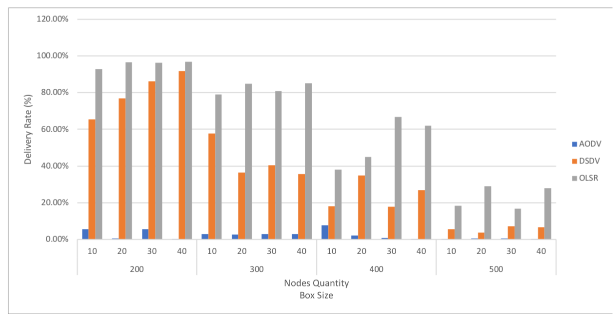

Figure 8: Delivery rate of each protocol in the scenario with Random WayPoint at 10m/s.

better performance when the density increases. In Figure 5, for example, the packet delivery rate increases concomitantly with the increase of the number of nodes for OLSR. In a 200 meter side box there is a clear increase in the delivery rate, reaching up to 97% in the case of 40 nodes in Gauss Markov.

There is, however, an irregular behavior. In the case of the 200-meter box, with random mobility and OLSR, the delivery rate starts at a very high 99.95% (10 nodes), decreasing until reaching 95% (40 nodes). In this case, the density may not have an influence. But, perhaps, its increase may overload the network and culminate in that slight variation in the delivery rate.

By analysing Figure 7 and 8, it can be noticed that DSDV has a inconstant behavior. It is not possible to define a clearly relation between the density and the delivery rate in these cases. Possibly, the influence of the mobility Random WayPoint versus the Gauss Markov is causing these irregular behavior.

5.1.3 Impact of Box Size. It is visible the difference that occurs when the side of the box is increased. This increase causes the network density drops drastically and, consequently, makes it difficult to find routes and maintain them. The performance drop is higher for DSDV, as the OLSR can maintain a near-70-80% delivery rate up to a 400-side box. The exception occurs in the case of Gauss Markov with a speed of 10m/s, when the performance drops to 50%.

5.2 Average Hop Count

The results obtained for average hops occurred in all scenarios are clearly related to the defined box size, and consequently to the distance between the sink and the source node. The bigger the box, the greater number of jumps occurred, as shown in Figures 9, 10, 11 and 12.

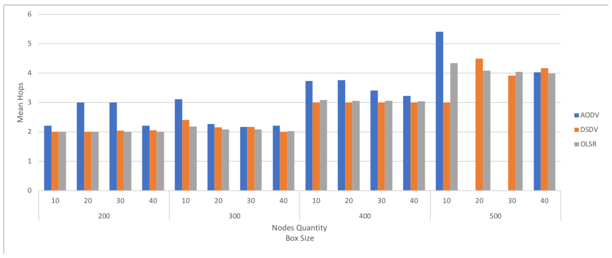

Figure 9: Average hop count of each protocol in the scenario with Gauss Markov at 5m/s.

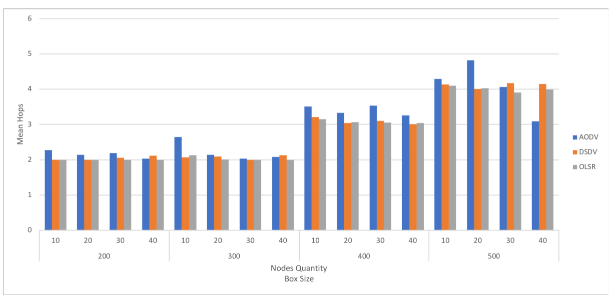

Figure 10: Average hop count of each protocol in the scenario with Random WayPoint at 5m/s.

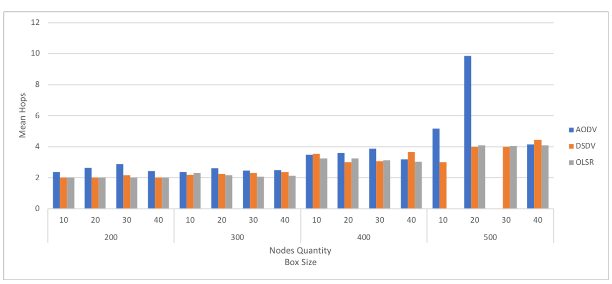

Figure 11: Average hop count of each protocol in the scenario with Gauss Markov at 10m/s.

Another relevant point for discussion is around transmission power. The power was chosen near the maximum stipulated by the 802.11n specifications - 20dbm. This power allows node to communicate with another or with the sink within a maximum distance of 150 meters. Thus, with a 200-side box, the node will be at a distance of approximately 280 meters. With this distance it is necessary at least two jumps between the source node and

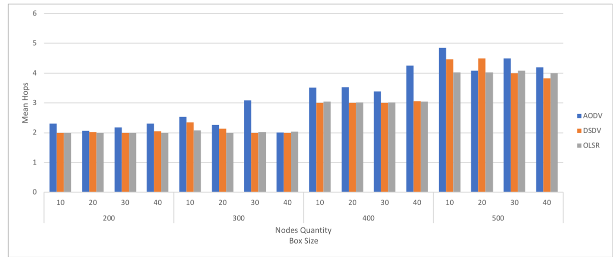

Figure 12: Average hop count of each protocol in the scenario with Random WayPoint at 10m/s.

the sink. This situation is evidenced in the graphs, which proves that the OLSR and DSDV protocols are finding the smallest route possible. AODV, on the other hand, has a higher average in some cases, evidencing the difficulty in searching for routes.

5.3 Throughput

In theory, the node that sends the packet only initiates the transmission when the route is previously traced. It is clear that AODV fails and the main reason is the difficulty in drawing a route and adapting to changes in topology. The DSDV and the OLSR, due their proactive, have the route already drawn. That is why both have high throughput, but there is a difference. While DSDV keeps the throughput rate high and constant, the OLSR has a variation depending on the network density. This is consequence of DSDV route removing from the routing table only if an update comes from its neighbor, whereas OLSR eliminates a route that is no longer active. Deleting the route causes the OLSR not to send the packet, creating the variation shown in Figures 13, 14, 15 and 16.

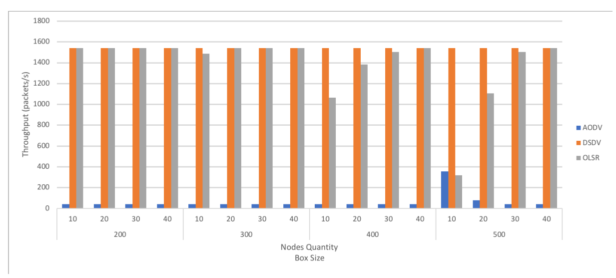

Figure 13: Throughput of each protocol in the scenario with Gauss Markov at 5m/s.

5.4 Average Delay

The graphs of Figure 17, which represent the average delay, have three interesting points. The first one is the influence of the network density, as the decrease in density leads to an increase in the delay. This becomes evident by increasing the box size, as in Figure 17, where the passage from 300 to 400 and even 500 meters only increases the delay.

Despite this increase, the delay of at most 300ms is not a factor that would difficult the proposed scenario. Sending a photo to the

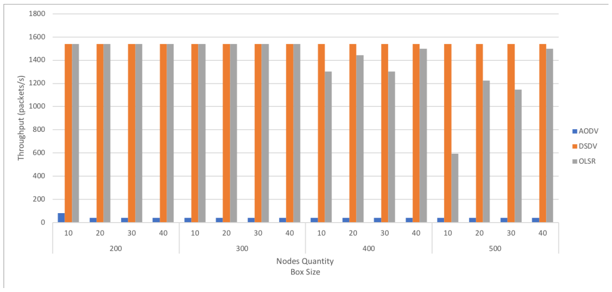

Figure 14: Throughput of each protocol in the scenario with Random WayPoint at 5m/s.

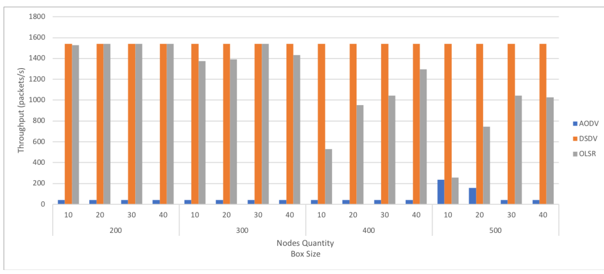

Figure 15: Throughput of each protocol in the scenario with Gauss Markov at 10m/s.

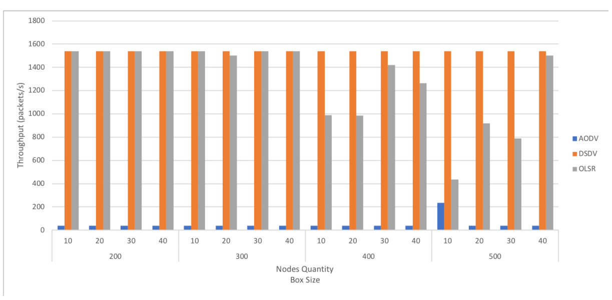

Figure 16: Throughput of each protocol in the scenario with Random WayPoint at 10m/s.

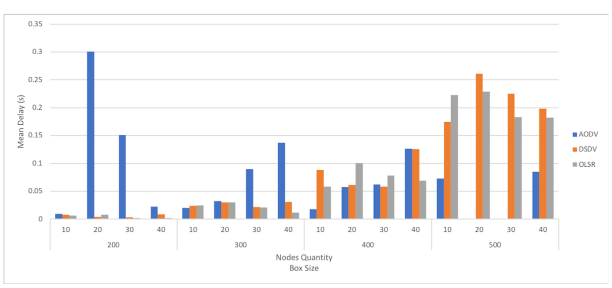

Figure 17: Average delay of each protocol in the scenario with Gauss Markov at 5m/s.

SINK for the purpose of being analyzed afterwards is not affected by a delay of this magnitude.

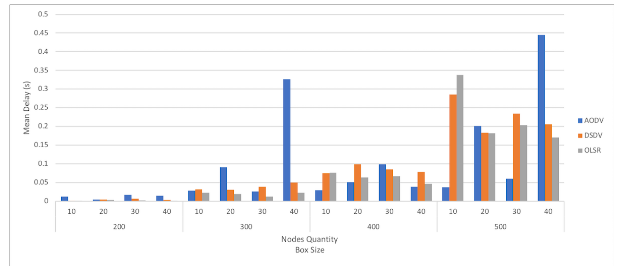

Figure 18: Average delay of each protocol in the scenario with Random WayPoint at 5m/s.

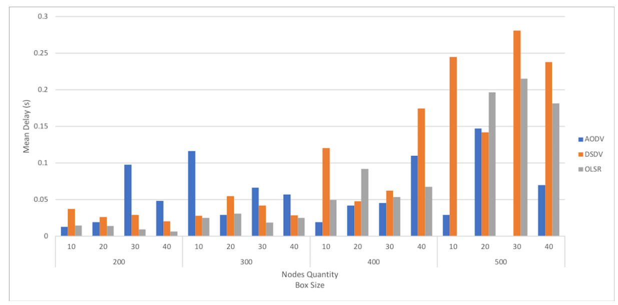

Figure 19: Average delay of each protocol in the scenario with Gauss Markov at 10m/s.

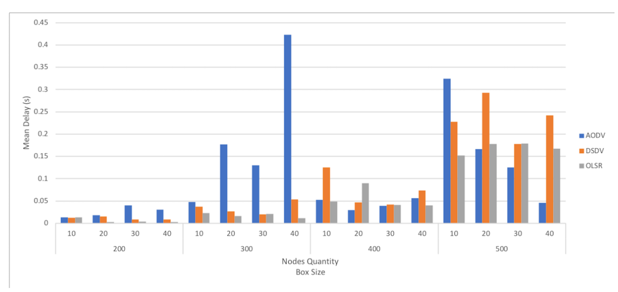

Figure 20: Average delay of each protocol in the scenario with Random WayPoint at 10m/s.

Another relevant point is the influence of speed. When comparing Figures 17 with 19 and Figures 18 with 20, can be perceived that an increase of the speed cause a growth on delay.

Finally, it is important to highlight the peaks that the AODV presents. This happens because the protocol loses a lot of time looking for the route.

5.5 Average Jitter

In the graphs of Figures 21, 22, 23 and 24 that shows the average jitter, it can verify the fact punctuated in the last paragraph. AODV has such a difficulty in finding routes that it is sometimes found quickly and in others it has a considerable delay. That's why there are peaks in the average jitter. The other two protocols don't present a significant value and can be despised in this case.

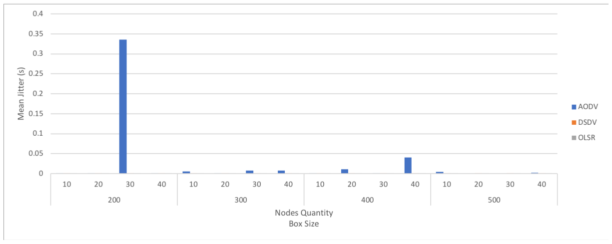

Figure 21: Average jitter of each protocol in the scenario with Gauss Markov at 5m/s.

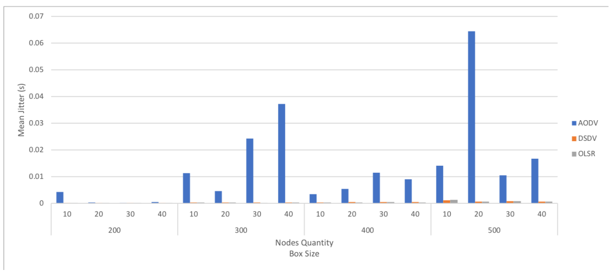

Figure 22: Average jitter of each protocol in the scenario with Random WayPoint at 5m/s.

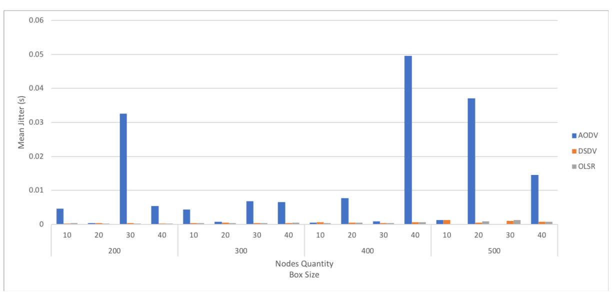

Figure 23: Average jitter of each protocol in the scenario with Gauss Markov at 10m/s.

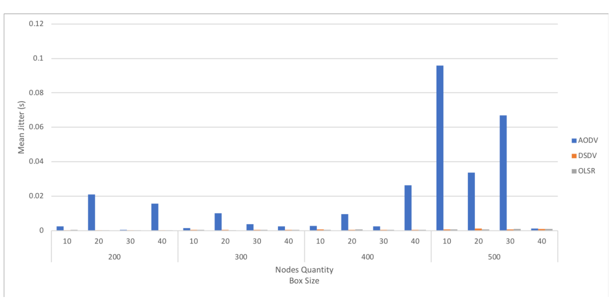

Figure 24: Average jitter of each protocol in the scenario with Random WayPoint at 10m/s.

6 CONCLUSION

In this research, the focus is to analyze performance of AODV, DSDV and OLSR routing protocols under different scenarios. Each scenario is defined by number of nodes, speed, mobility model and the box size. The parameters influence on the performance is analyzed under the follow outputs: Throughput, Delivery Rate, Average Delay, Average Jitter and Mean Hops.

Through the simulation results is evident that AODV does not achieve a minimally reasonable performance in any scenario. So this protocol is not feasible for the FANET paradigm. In other hands, OLSR and DSDV, can be considered feasible. Although the DSDV shows a performance drop when the speed is 10m/s and the box size increase, in the scenario of 5m/s and 200-size box it perform better than OLSR. All other scnarios, OLSR is the protocol that has the best performance. According to these results, it's possible to claim that proactive protocols have a better performance in dynamic topologies than reactive protocols.

In future works, the intention is to study new possibilities. Check the real impact that the loss rate can generate on image streaming and if the change of the transport protocol, UDP to TCP, can optimize it; Evaluate the impact that control packets can generate; Study the feasibility of a SDN solution for FANET [6]; Propose a new mobility model that allows a peer to peer connection between the nodes or between the network edge node and the sink.

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