Chapter

Wireless Communications Challenges to Flying Ad Hoc Networks (FANET)

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Abstract

The increasing demand for Internet access from more and more different devices in recent years has provided a challenge for companies and the academic community to research and develop new solutions that support the increasing flow in the network, applications that require very low latencies and more dynamic and scalable infrastructures, in this context the mobile ad hoc networks (MANETs) emerged as a possible solution and applying this technology in unmanned aerial vehicles (UAVs) was developed the flying ad hoc networks (FANETs) which are wireless networks independent, its main characteristics are to have high mobility, scalability for different applications and scenarios and robustness to deal with possible communication failures. However, they still have several constraints such as limited flight time of UAVs and routing protocols that are capable of supporting network dynamics. To analyze this scenario, two simulations were developed where it was possible to observe the behavior of FANET with different routing protocols both during data transmission and video transmission. The results show that the choice of the best routing protocol must take into account the mobility of the UAVs and the necessary communication priority in the network.

Keywords: FANET, UAV, routing, protocols, QoS, QoE

1. Introduction

The mobile ad hoc networks (MANETs) have evolved significantly in recent decades, where the differential of this type of network is the independence of a centralized infrastructure to organize flow, a router or switch, for example, so if any device present in this network is disconnected or damaged, it can automatically adjust to a new topology, and the routing tables are updated [1].

From the freedom provided by the MANETs, several other devices have started to be connected to the Internet in addition to cell phones, tablets, and notebooks, so that together with wireless sensor networks (WSN), they can play an essential role in the development of applications aimed at Internet of things (IoT) [2].

Among these devices, stand out cars, other types of cars and the highway itself in which they are, i.e., using a MANET network to connect them is the first step toward the creation of autonomous vehicles, vehicular ad hoc networks (VANET), for further study, see [3–5].

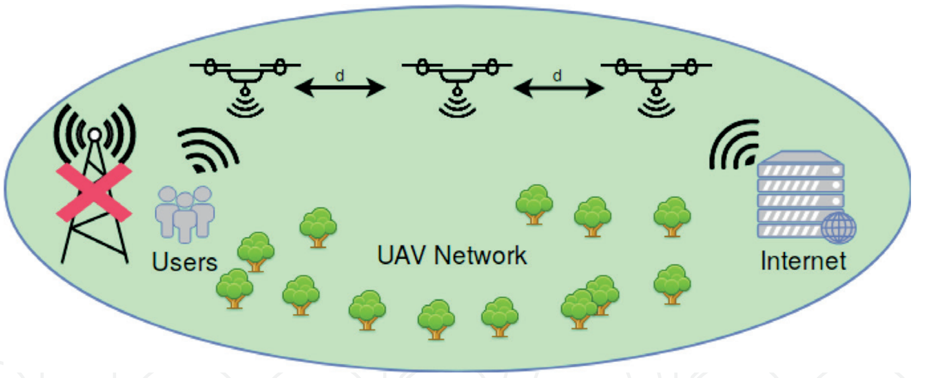

Figure 1.
FANET replacing LTE antenna.

They represent a major advance in mobile network technology in general, since several routing protocols have been developed or adapted for this type of network [6]. In addition, maintaining the quality of service (QoS) even at the high speed that the vehicles reach is one of the main challenges to be overcome in this area.

More recently, because of the popularization and cost reduction of unmanned aerial vehicles (UAVs), flying ad hoc networks (FANETs) [7–11] have emerged, which are networks composed only of aerial devices that can communicate between UAV-to-UAV and other ground-based UAV-to-ground devices. According to [12] UAVs can be divided into UAVs of high-altitude and long-range and medium-range, small drones and mini drones, the first two being military. In this chapter only the small drones and mini drones will be addressed.

The FANETs can operate either independently and by transmitting the flow received from land-based devices to a remote server or can also support other types of networks, for example, via satellite or cellular, if they are overloaded or unavailable as shown in **Figure 1**.

Therefore, such technology can play an essential role in the next generation of cellular networks, offering future support to 5G networks [13, 14], which it will reach very high speed and minimum latency, but due to the higher frequency in which they operate, the range is limited in relation to 4G. Thus, FANETs present themselves as a low-cost, scalable solution for maintenance and expansion of the Internet infrastructure worldwide, and it is essential to research, simulate, and validate their utility in different applications, taking into account the limitations of both UAVs and network itself.

In this chapter the main challenges for the implementation of FANETs in Section 2 will be addressed; in Section 3 the applications that can use the FANETs will be discussed and classified according to their characteristics, and Section 4 will address several available routing protocols and their advantages and limitations. Finally, Section 5 will demonstrate simulations of FANET behavior in different scenarios and routing protocols with data transmission and video.

2. Challenges

Despite several advances in recent years, FANET networks still have restrictions that may be critical to their operation depending on the application. The main one is energy consumption [15–17] because it limits the flight time of the drones, the speed of connection, and the range of the signal transmitted by them, so the challenges that need to be overcome to make FANET a reality involve primarily the search for solutions to these limitations, and in addition other factors can affect the performance of the network as the mobility and storage capacity of the drones. Possible solutions to these challenges will be discussed below.

Directional antennas: Most router antennas are omnidirectional, that is to say that the signal transmitted by them is sent equally in all directions, but when using these same antennas in drones, the results may not be very efficient as regards the quality of the antenna and energy consumption. Therefore, new antennas have been developed with beamforming technology [18, 19]; this change allows the transmitted signal to be directed to a specific area close to the UAV as shown in **Figure 2**. In this way the signal quality at the specific location is significantly better, and the energy consumption of the UAV is also reduced. However, it is still relatively a new technology and still needs to be better evaluated and implemented.

Mobility: One of the biggest differentials of UAVs is the high mobility and speed variation they have, which allows them to access hard-to-reach places and travel long distances in a short time, depending on the UAV model.

Thus, regardless of the mode of operation of the drones being both fully autonomous and controlled by a base station, it is necessary that critical information for the mobility of one or more drones is transmitted to the other drones in the network or to the base station as prevention alerts collision, GPS, flight time, environmental and climatic conditions, as well as the transmission of drone drive commands if they are controlled by a base station (**Figure 3**).

Routing protocols: Routing protocols are the brain of FANETs and control all flow both between UAVs and other devices connected to them, and although there are already several routing protocols available, these protocols sometimes cannot cope with mobility and the speed of the UAVs which causes a high rate

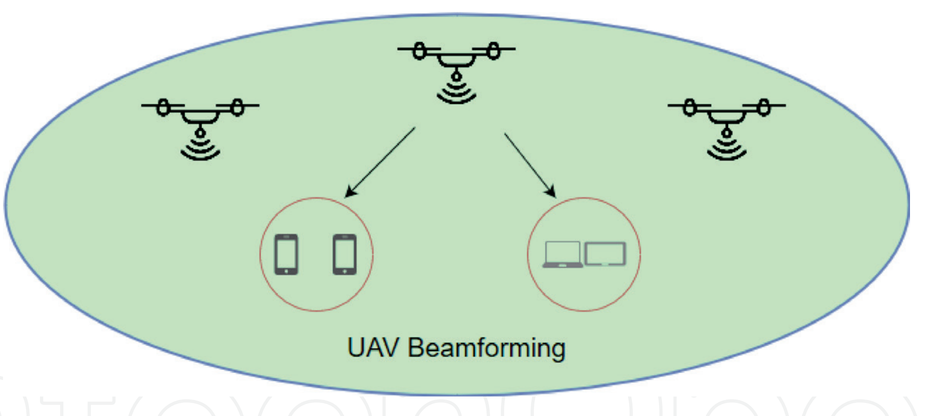

Figure 2.
UAV signal beamforming.

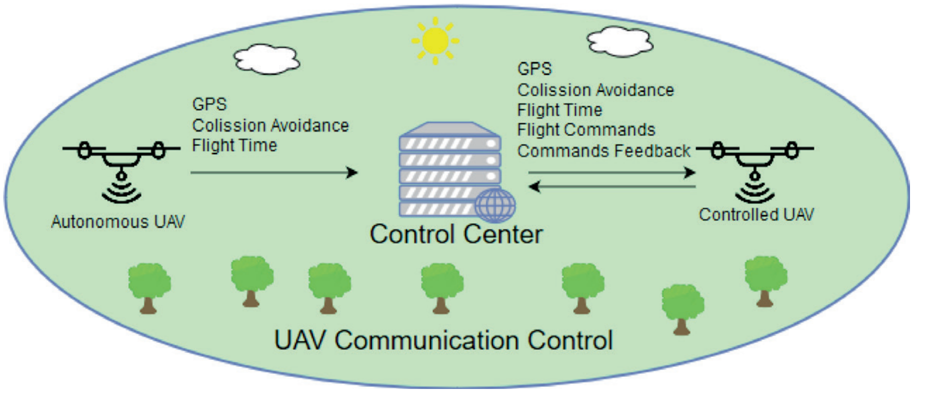

Figure 3.
UAV communication scheme.

of errors in the connection and until the drop of the network in certain cases. In this way, new protocols were developed with the focus on mobile ad hoc networks, with FANETs being one of them, and just like beamforming, these protocols are still being tested but at a later stage. Because the evaluation of routing protocols is one of the main research focuses in FANETs, it will be addressed in more depth in Section 4.

3. Applications

Due to its physical and architectural characteristics, there are several applications for FANETs. Some of them are mentioned in different scenarios.

3.1 Disaster monitoring

In some cases of disasters, a human being may encounter obstacles that prevent the analysis of the entire affected area. In this situation, it is possible to use FANETs to evaluate the scenario completely [7].

3.2 Monitoring of agricultural areas

There are several possibilities for the use of FANETs in agriculture such as complete crop evaluation, plant health analysis, and mapping of possible areas for planting expansion (**Figure 4**) [7].

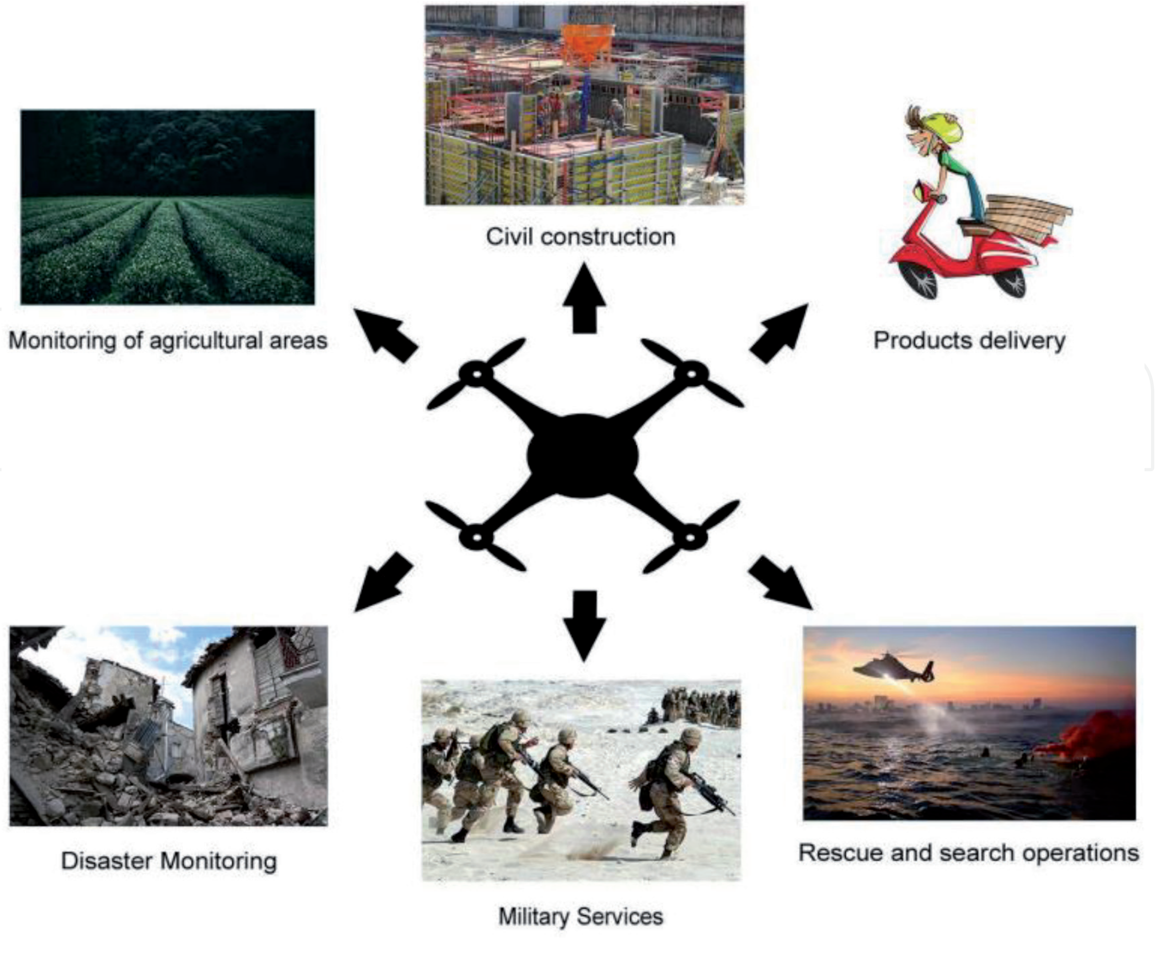

Figure 4.
FANET applications.

3.3 Search and rescue operations

In rescue situations where conventional mobile networks are damaged, the FANETs can be used to search for hostages in the affected area. And, because of the size of the UAVs, it is possible to access places in which a human would have difficulty [9].

3.4 Sensor networks

Sensor networks are mainly used for data collection and can be used together with FANETs in various situations [20]. Due to the ease of the UAVs to access any location without great difficulties, there will be an improvement in the performance of the networks when evaluating the scenarios in which they are applied [9].

3.5 Construction

With the use of FANETs, it is possible to analyze constructions, verify their progress and their quality, and also evaluate in advance the conditions of the environment to be used for the work in order to prevent possible calamities [7].

3.6 Product delivery

In order to reduce their costs and improve the quality of their services, some companies already idealize the use of UAVs for product delivery [7]. The service will be done autonomously through the implementation of an intelligent system in the UAVs [21].

3.7 Military service

The FANETs are widely used by military personnel primarily for communication between soldiers or between their barracks. It also can be used in civil operations to maintain the security of society [9].

4. Protocols

Due to some characteristics such as high mobility, the constant changes in network topology, unpredictable environmental and climatic factors, and energy consumption, the communication of nodes in FANETs becomes a challenge [7]. The nodes represent communication points in the networks, being computers, servers, or, in the case of FANETs, UAVs [22]. Therefore, in order for the network to have the desired performance, it is necessary that the routing protocols are adequate to handle various scenarios and conditions [23]. Here are the three types of protocols used in FANETs, which are proactive, reactive, and hybrid (**Figure 5**).

4.1 Proactive

Proactive protocols are those that update their routing tables at fixed time intervals. This feature allows the packets to be sent faster through the network because the nodes already know the changes in the routes [23]. The disadvantage of this type of protocol is the need for greater bandwidth to make constant updates [7]. The two main proactive protocols for FANETs are:

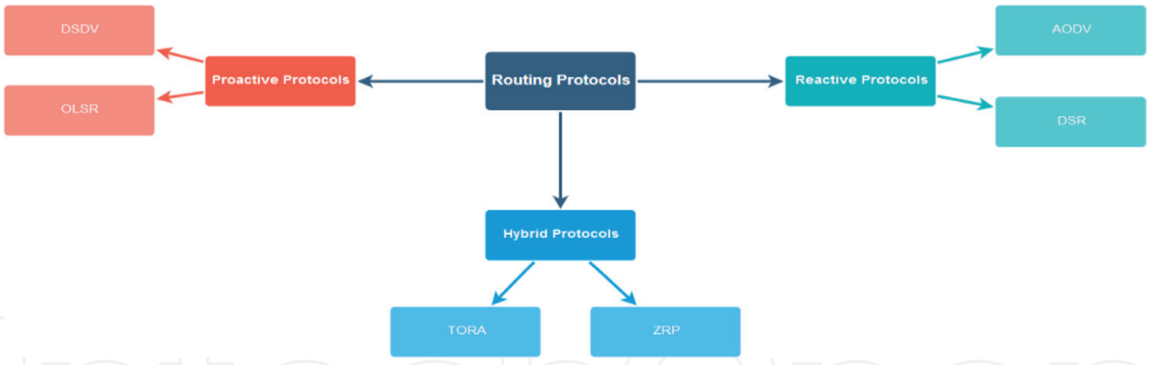

Figure 5.
Ad Hoc Routing Protocols.

4.1.1 Optimized link state routing (OLSR)

The OLSR is a specific protocol of ad hoc networks, and it has the main characteristic to select some nodes of the network to act as relays, called multipoint relay (MPR) [24]. The purpose of this mechanism is to avoid flooding in the network, caused by the excess of packets received by each node [25].

4.1.2 Destination-sequenced distance vector (DSDV)

In the DSDV protocol, in addition to the information of the network itself, the routing tables contain a sequence of numbers that changes according to the network topology [3]. These numbers are sent to all the nodes of the network, keeping them always updated, in order to avoid loops occurring between the nodes [23].

4.2 Reactive

Unlike the proactive ones, the reactive protocols only establish communication in the network when requested by the nodes [7]. Due to this feature, routing tables are only updated when there are packets to be sent [23]. Therefore, since it is necessary for the node to search the route before sending the package, the time to complete the entire process until the delivery is made becomes greater [9]. For use in FANETs, the following protocols are proposed:

4.2.1 Ad hoc on-demand distance vector (AODV)

The AODV protocol first makes the discovery of routes when necessary to send a packet and stores that route, just after the packet is sent to its destination [26]. In addition, because it is a mobile network protocol, if there is a connection interruption, the maintenance of routes starts to update the routing tables and thus maintains the communication between the nodes [24].

4.2.2 Dynamic source routing (DSR)

The DSR is a widely used protocol in multi-hop wireless networks, and it has the feature of its source node storing the entire route up to the destination node [24]. As the AODV, the DSR protocol also performs route discovery when there is a need for communication between two nodes to send packets [27]. And it performs maintenance of routes if there is a change in the topology of the network and communication is interrupted [24].

4.3 Hybrid

The hybrid protocols are the combination of reactive and proactive protocols, using the best resources of each, being used mainly for large networks [24]. They are based on the concept of zones, where proactive protocols are used for intra-zone routing (nodes within the same zone) and reactive routing protocols are used for inter-zone routing [23]. The main protocols of this type are:

4.3.1 Zone routing protocol (ZRP)

In this protocol, each node has a different zone, so the neighboring node zones overlap [24]. In intra-zone routing, proactive protocols are used to maintain the routes; due to this, if the source and destination nodes are in the same zone, packet sending is done immediately [23]. Already in the inter-zone routing, we use reactive protocols to find the routes and maintain them [23].

4.3.2 Temporarily ordered routing algorithm (TORA)

The TORA protocol is characterized by each node of the network maintaining only the routing information of its neighbors updated [23]. Because it is a highly adaptive protocol, its reactions to network topology changes are reduced in order to minimize the propagation of control messages, so the network does not look for new routes when there is no need [24]. The TORA mainly uses reactive protocols but also uses proactive protocols in some situations [23].

5. Performance evaluation

The performance of FANET networks can be analyzed through computer simulations. In order to correctly evaluate these network types, two scenarios were simulated to simulate different transmission types, and each one used three of the aforementioned routing protocols: AODV, OLSR, and DSDV [28].

The network simulator 3 (NS-3) software was used for the construction of simulation scenarios based on C++ language [29]. Each simulation has specific parameters that constitute different situations for this type of network. The details of each scenario were defined according to **Tables 1** and **2**.

The scenario of **Table 1** is to evaluate the performance of packet flow between UAVs and a server; this type of application is very common in a network of sensors for data collection or monitoring. In this scenario, all drones send data to the server at the same time and vice versa.

The scenario in **Table 2** seeks to evaluate the performance of a video transmission between a drone and a server; this type of application is widely used in disaster monitoring and rescue in locations inaccessible by the ground. In this scenario, a drone flies on a certain space while transmitting a video to the server on the ground.

5.1 Simulation parameters

Different types of simulation parameters were considered for each of the analyzed scenarios. In simulation 1, three network performance parameters were considered: packet received rate, delay, and network throughput. In simulation 2, only a few parameters were considered in relation to simulation 1, the received packet rate and the delay. However, the video transmission that occurs in this scenario requires specific quality of experience (QoE) parameters to be analyzed, such as structural similarity (SSIM), signal peaks (PSNR), and video quality metrics (VQM).

5.1.1 Packet delivery ratio

This parameter is defined by the ratio between the number of packets that are sent and the number of packets that are actually received at the destination. The final fee is displayed as a percentage based on total packets sent.

Simulation 1: UDP flow on a FANET network with UAVs	
Parameter	**Value**
Simulation time	60 s
Simulation area	400 × 400 × 400 m^2
UAVs' quantity	4
UAVs' speed	0–15 m/s
Mobility model	Gauss-Markov
Transmission range	40 m
MAC protocol	IEEE 802.11a
Routing protocols	OLSR, AODV, and DSDV
Transport protocol	UDP
Internet protocol	IPv4
Maximum transmission rate	100 kbps
Packet size	512 bytes

Table 1.
Simulation parameters for QoS.

Simulation 2: Streaming video on a FANET network with UAVs	
Parameter	**Value**
Time simulation	80 s
Simulation area	400 × 400 × 100 (L × P × A) m^2
UAVs' quantity	1
UAVs' speed	0–15 m/s
Mobility model	Gauss-Markov
Transmission range	40 m
MAC protocol	IEEE 802.11b
Routing protocols	OLSR, AODV, and DSDV
Transport protocol	TCP
Internet protocol	IPv4
Application	Evalvid
Video	st_highway_cif.st

Table 2.
Simulation parameters for QoE.

5.1.2 Delay

This parameter is defined by the amount of time a packet takes to traverse from the source to the destination in a transmission. Several factors directly influence this parameter, such as the routing protocols and the transmission rate of the network.

5.1.3 Throughput

This parameter is defined by the bandwidth of a transmission between two nodes of a network over time. It is generally expressed in bits/sec.

5.1.4 Structural similarity (SSIM)

It is a method used to measure the similarity between two images, determining the quality of the image received in the transmission [30]. In simulation 2, because it is a video, each frame receives a specific value. The SSIM metric was developed to extract structural characteristics of images, configuring the proximity between the pixels as a key factor to quantify the structures and to approach the visual quality of the images.

5.1.5 Peak signal-to-noise ratio (PSNR)

It is defined by the ratio between the signal power and the noise introduced by the transmission thereof [31]. In the case of video transmission, this noise influences the fidelity of the video representation at the destination. The PSNR is an approximation of human perception of the quality of reconstruction and is generally measured in decibels (dB).

5.1.6 Video quality metric (VQM)

This parameter is defined by the perceptual defect measurements of various video deficiencies, such as blur, rough motion, overall noise, block distortion, and color distortion. These measures are combined into a single metric that provides an overall quality forecast [32].

5.2 Results

In order to obtain the data, it is essential to organize and manipulate this data in a correct way, in order to analyze the performance of each parameter individually, considering the relation between them. In both scenarios, the flow monitor capture library [33] was used, which enabled the capture of the discrete-time performance parameters in each stream in the simulation scenario.

It was necessary to treat the data of the video transmission made by Evalvid in simulation 2 to extract the metrics of the network as delay and loss of packages. In order to obtain the PSNR and SSIM metrics, it was necessary to use the MSU Video Quality Measurement Tool (MSU VQMT), which reconstructs the transmitted video and compares it with the original Evalvid library video [34].

5.2.1 Simulation 1: UDP flow on a FANET network with UAVs

Comprising four UAVs and one server, the scenario simulates UDP packet flow between the server and the UAVs, which is initially in the server sense for UAVs (download) and UAVs for the server (upload).

Two graphs were generated for each analyzed parameter, one for upload flow and the other for download flow. Each displayed data represents the average of all the flows captured at that instant of time. After 60 seconds of simulation, all the performance parameters were analyzed.

5.2.1.1 Packet delivery

The received packet rate had similar results in both directions of flow. **Figure 6** shows the performance in the upload; the OLSR had the best performance, remaining above 70% in most of the simulation; on the other hand, the DSDV showed the worst performance, remaining below 40% in almost all the simulation.

In the download flow, the protocols had similar results throughout the transmission. The biggest difference between them can be seen in stability, especially the OLSR, which has remained stable close to 70% in most of the transmission. The AODV protocol exhibits poor performance in the initial simulation period, due to the reduced routing table of the protocol, which updates according to the need for transmission (**Figure 7**).

5.2.1.2 Delay

The resulting delay in the upload flow was noticeable only in the OLSR protocol, due to the common overhead of the proactive protocols [25]. On the other hand, in the download flow, the result was equivalent in all the protocols, concentrating the

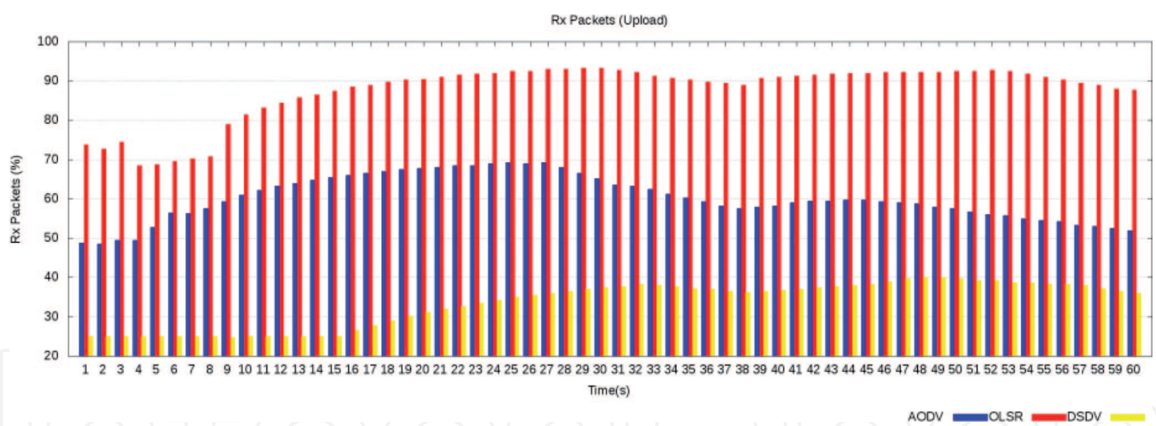

Figure 6.
Received packets in upload.

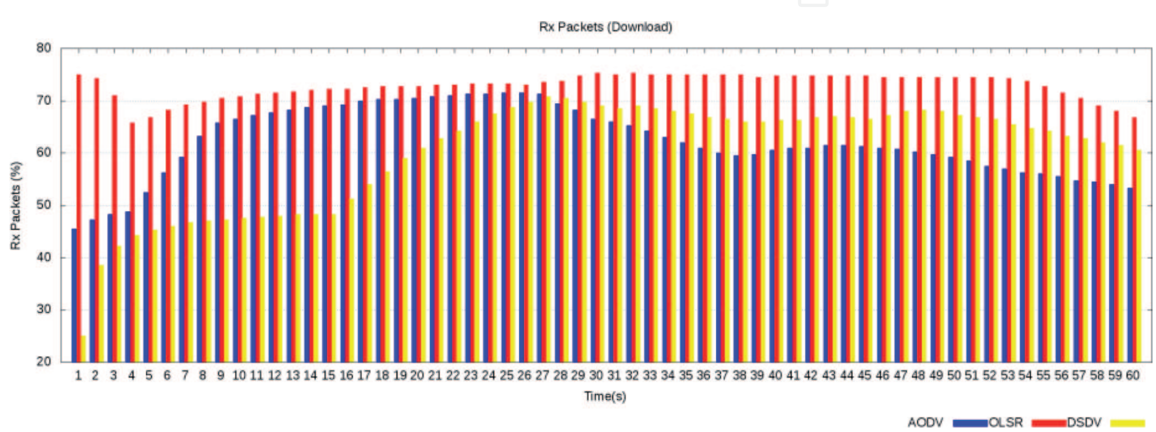

Figure 7.
Received packets in download.

greater delays at the beginning and the end of the transmission. Despite the high mobility of the drones, the delay had good results in download flow, in which no routing protocol exceeded 60 ms, as can be seen in **Figures 8** and **9**.

5.2.1.3 Throughput

The protocols performed differently depending on the flow direction. In the upload flow, shown in **Figure 10**, the OLSR had the highest average bandwidth between the protocols tested; on the other hand, the AODV and DSDV stabilized below half of the available maximum bandwidth, damaging the packet delivery, as previously seen in **Figure 6**. In the download flow, all the protocols have stabilized over time, since there being only one transmitter and several receivers, the packet flow became simpler, improving the overall performance of the protocols (**Figure 11**).

5.2.2 Simulation 2: streaming video on a FANET network with UAVs

Comprised of one UAV and one server, simulation 2 performs a video transmission between the server and the sleeping device. With the help of the Evalvid utility for NS-3, it was possible to analyze performance parameters and quality of experience (QoE) in all frames of the video, resulting in a detailed capture of protocol performance in this scenario. One was generated for each performance parameter, and four graphs for each QoE parameter.

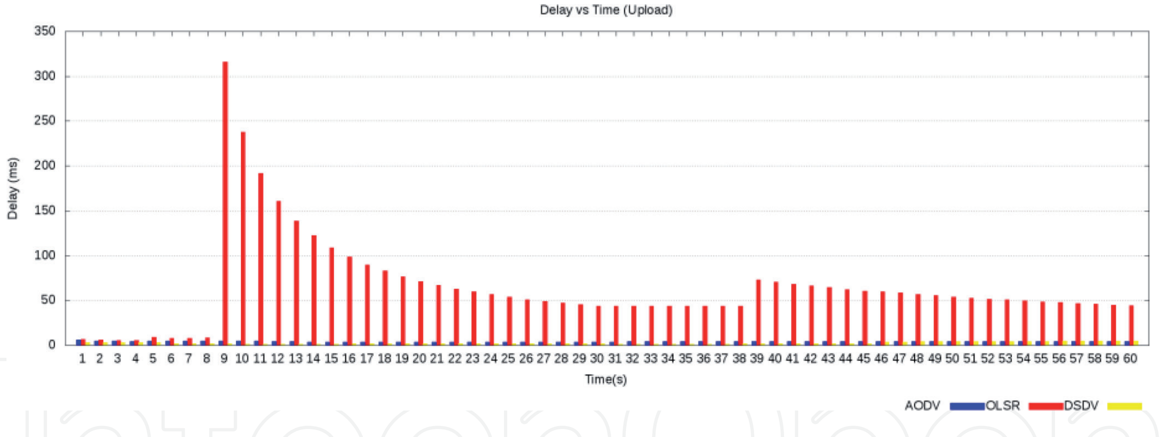

Figure 8.
Delay packets in upload.

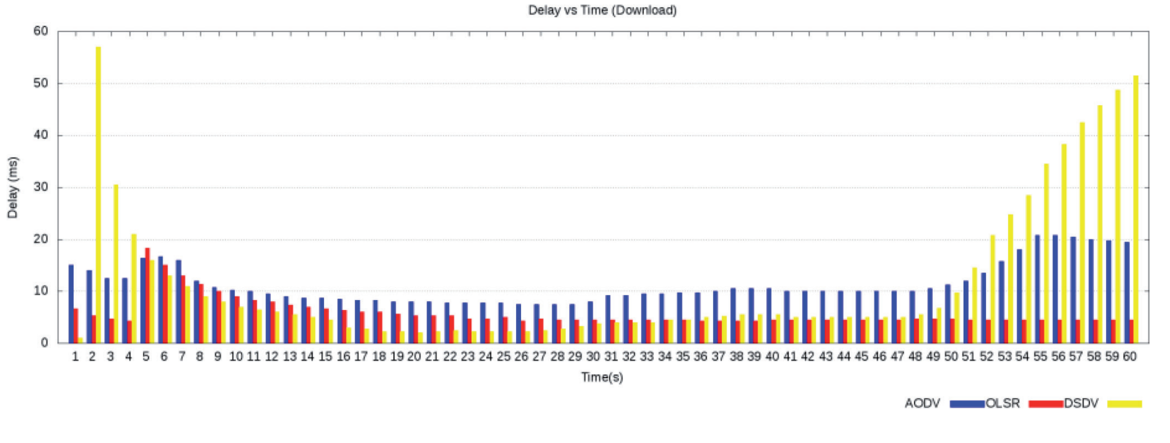

Figure 9.
Delay packets in download.

5.2.2.1 Packet delivery rate

The AODV and OLSR protocols had similar results along the transmission, with a higher performance in the first 17 seconds, followed by a significant decay due to the mobility of the FANET. The DSDV had the worst performance, as a result of an even greater decline, with no significant stability (**Figure 12**).

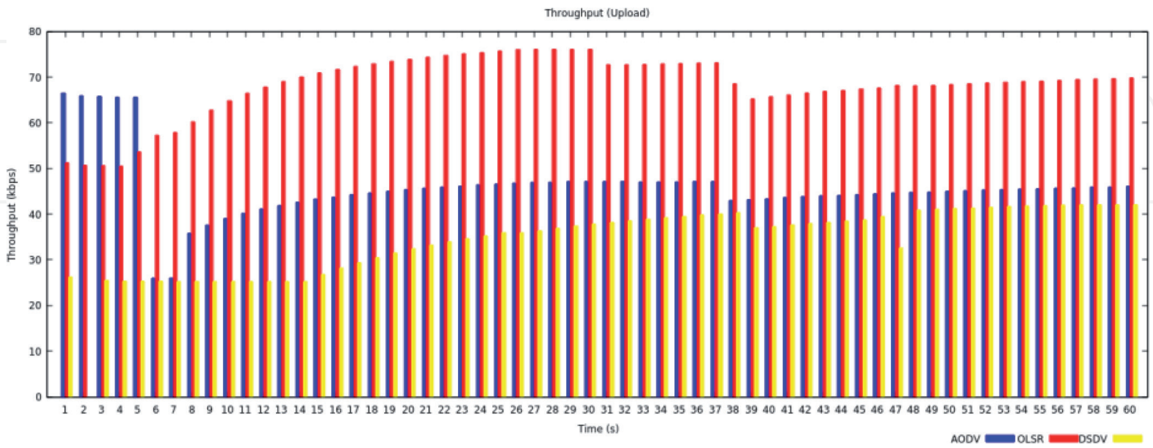

Figure 10.
Throughput in upload.

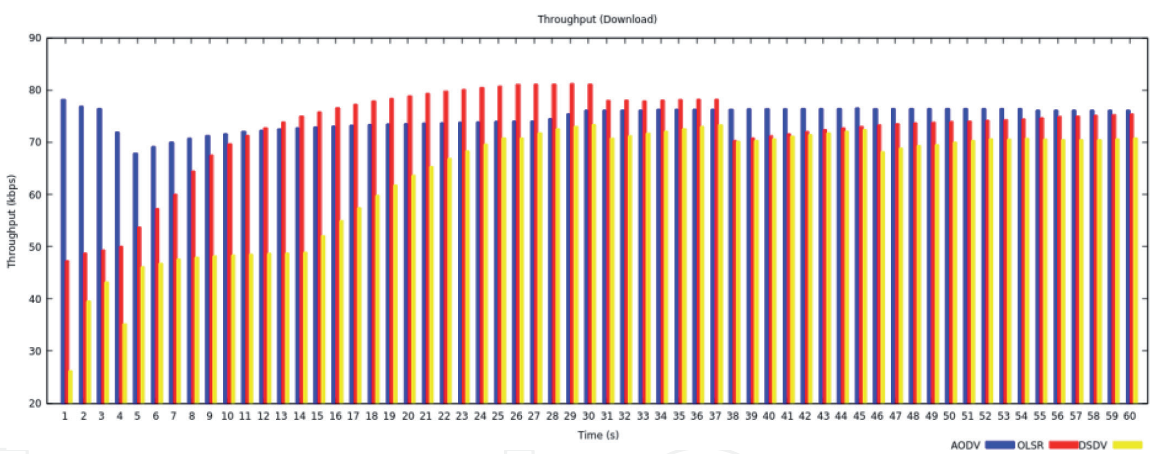

Figure 11.
Throughput in download.

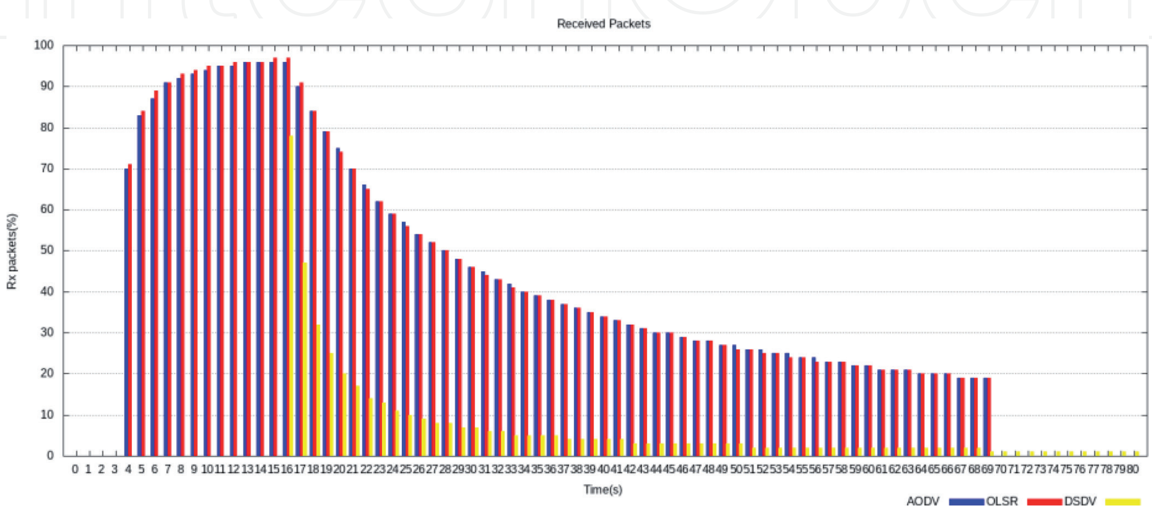

Figure 12.
Received packets in video application.

DOI: http://dx.doi.org/10.5772/intechopen.86544

5.2.2.2 Delay

The delay was well-designed in all protocols, which stabilized throughout the transmission. The main factor that contributed to the result shown in **Figure 8** was the implementation of the Aar WiFi Manager function in simulation 2, an algorithm that works on the physical layer of the NS-3, which controls the transmission rate in the network [35]. With values below 3 ms in most of the transmission, the delay cannot be considered one of the reasons for packet loss (**Figure 13**).

5.2.2.3 Structural similarity (SSIM)

Figure 14 shows the mean SSIM in each protocol, which may have values of maximum 1 and have a minimum of 0.994 and a maximum of 0.998, highlighting a very low variation in transmission quality.

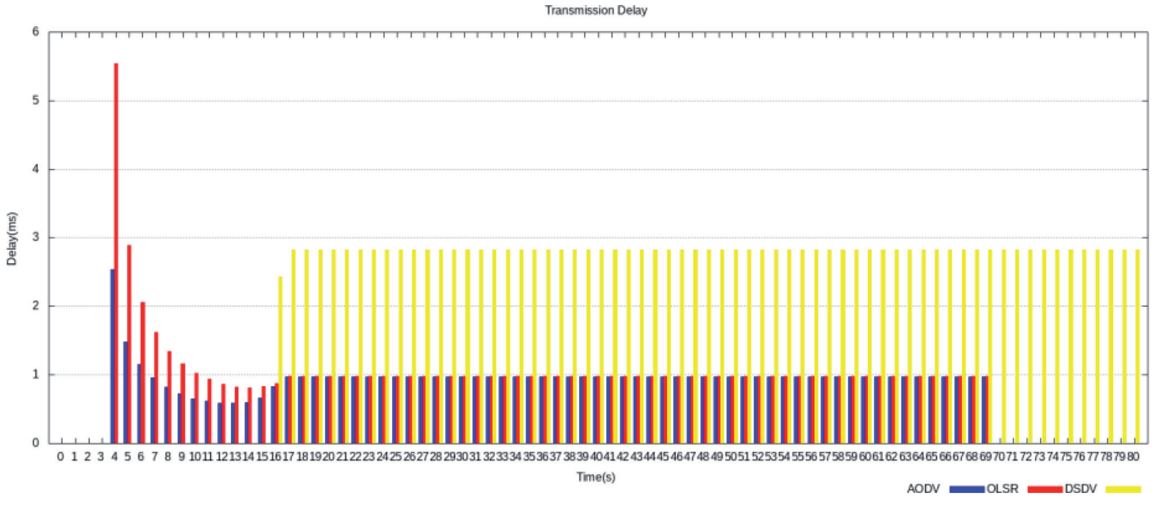

Figure 13.
Delay in video application.

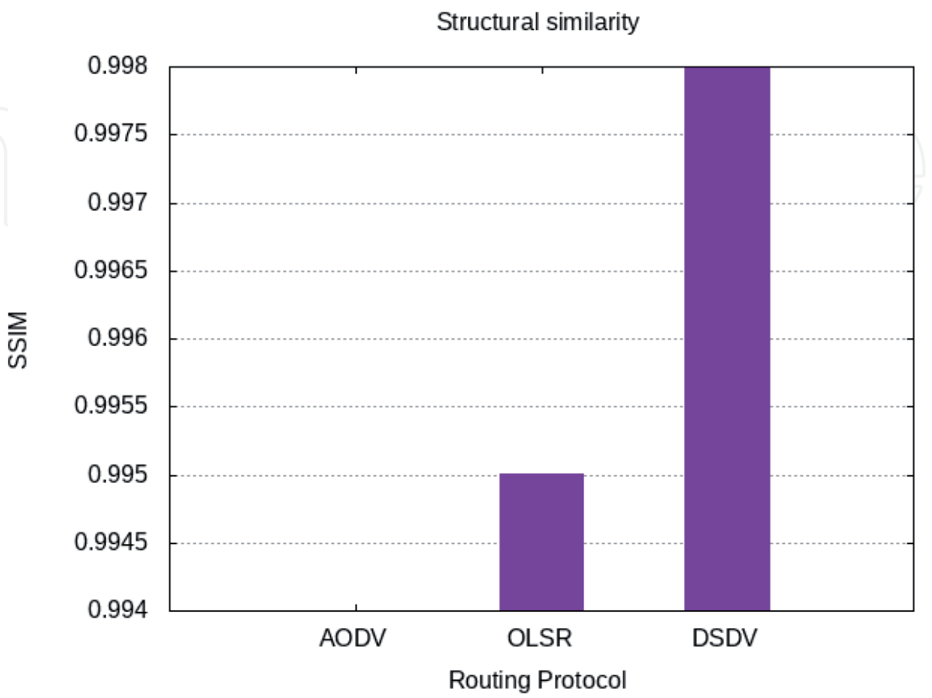

Figure 14.
SSIM average values.

Figures 15, **16**, and **17** show the SSIM value in each frame of the video, further emphasizing the similarity in performance between the protocols. Thus, the routing protocols did not interfere directly in this metric; this was due to the direct

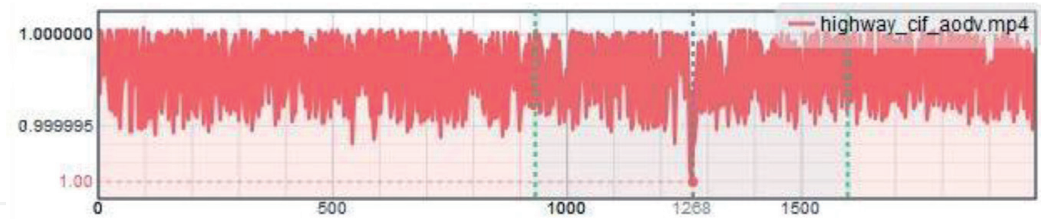

Figure 15.
SSIM to AODV protocol.

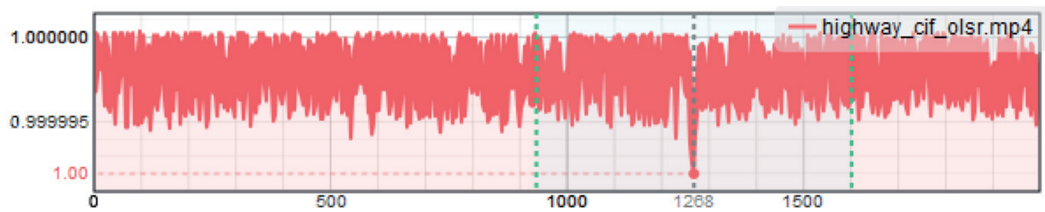

Figure 16.
SSIM to OLSR protocol.

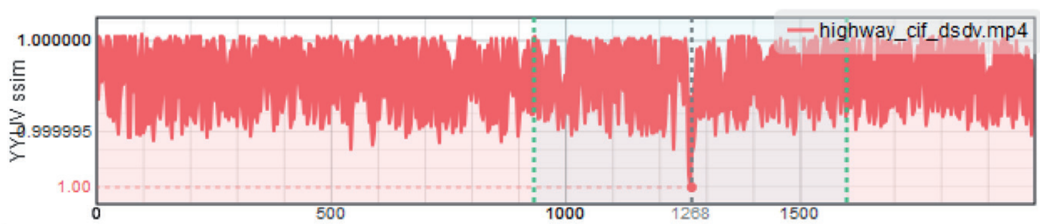

Figure 17.
SSIM to DSDV protocol.

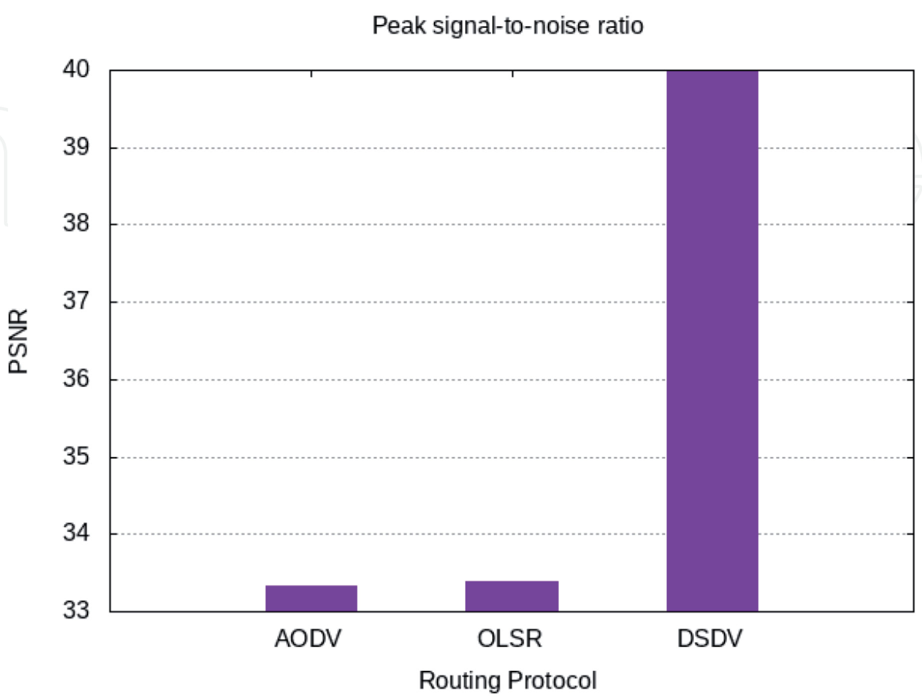

Figure 18.
PSRN average values.

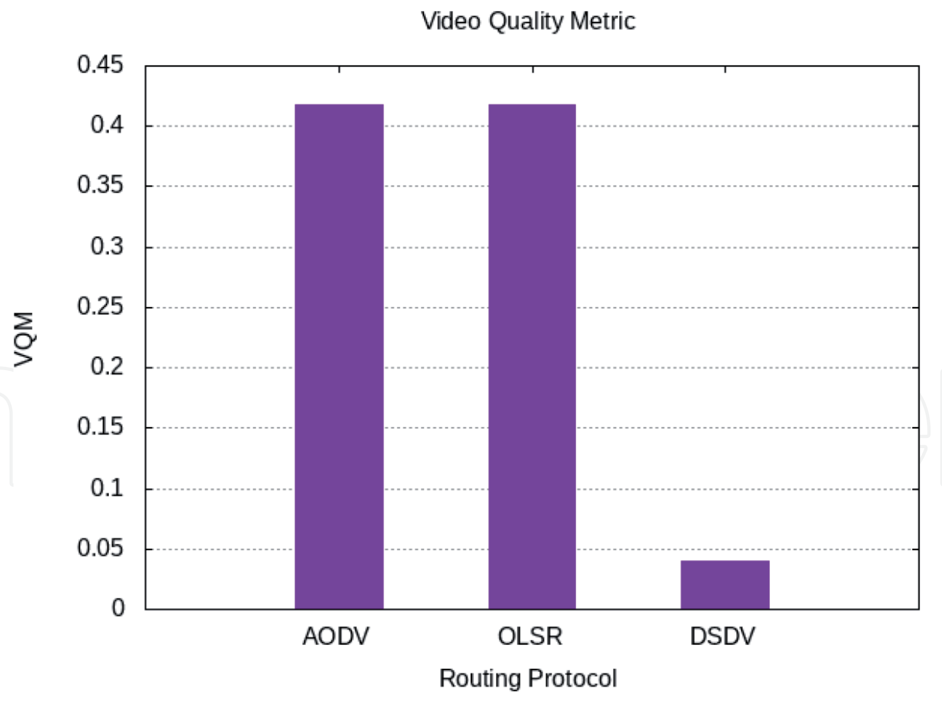

Figure 19.
VQM average values.

connection between drone and server during the simulation, without the need to perform much jumps in the network.

5.2.2.4 Peak signal-to-noise ratio (PSNR)

The PSNR shows the relationship between signal and video noise where a higher ratio means better quality. According to **Figure 18**, the DSDV obtained the best result, well above the other protocols, which are almost 7 dB difference, a significant value in this metric because it is a logarithmic scale.

5.2.2.5 Video quality metric (VQM)

The resulting VQM of **Figure 19** composes a correlation between seven different video quality parameters. The results show a low correlation coefficient in the AODV and OLSR protocol tests of slightly more than 0.4 between the original and transmitted videos. With the DSDV protocol, the resultant was even worse, with a value <0.05 correlation. In visual perception, this disparity results in a significant loss in video quality, something that was not shown in the other QoE parameters.

6. Conclusions

The evolution of the FANETs will allow a new range of application of this network, making several other devices connected to the Internet, such as sensors, cars, etc. Soon, FANETs will be essential for the construction of interim air networks. The applications discussed in this chapter have demonstrated the high flexibility of such networks, such as the use in rescue and monitoring, smart grids, etc. The challenges present in the FANETs are limited to problems in energy efficiency and routing protocols as seen in the simulations.

Due to the high mobility and flexibility of the UAVs, it is difficult to guarantee efficiency in all cases; simulations 1 and 2 have shown that proactive protocols are more efficient in scenarios that communicate with an onshore server but may not be the case in limited broadcasts or mobile server, which may have longer delays due to the frequent updating of the routing tables and the high mobility of the UAVs, which cause frequent loss of connection.

Acknowledgements

The authors also acknowledge the financial support by PROPESP/UFPA.

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