# Unmanned Aerial Vehicle Networking Protocols

**Conference Paper** · January 2016

DOI: 10.18687/LACCEI2016.1.S.078



**2 authors:**

Catalina Aranzazu Suescun
Latin American and Caribbean Consortium of Engineering Institutions



Mihaela Cardei
Florida Atlantic University

# Unmanned Aerial Vehicles Networking Protocols

Catalina Aranzazu Suescun, MSc, Mihaela Cardei, PhD, Mentor
Florida Atlantic University, United States, caranzazusue2014@fau.edu, mcardei@fau.edu

***Abstract*—Unmanned Aerial vehicles (UAV), more commonly known as *drones*, are widely used by military and civilian applications. They can be used for remote sensing, transportation, scientific research, armed attacks, search, and rescue. They can be used in applications where human presence is dangerous. Drones could be equipped with cameras, sensors, communications equipment, and weapons. UAVs can be piloted by a human from land or can be autonomous. In the future, autonomous UAVs will work collaboratively with other aircrafts. UAVs can communicate wirelessly, forming a MANET. Thus the constraints and advantages of MANETs are transferable to networks of UAV. This paper presents some networking protocols for the UAV wireless networks.**

***Keywords—Communication, Networking, Unmanned Aerial Vehicles.***

## I. INTRODUCTION

UAV is the acronym of Unmanned Aerial Vehicle, that refers to a pilotless (no human crew on board) aircraft. They can be operated remotely by a human or be autonomous [1].

UAVs have been used since 1903 when the first UAV was developed to be used in combat and surveillance. Some authors argue that balloons are the first UAVs, but the really introduction of UAVs was during the World War I when the US army used them in combat in order to reduce the number of pilot casualties. During the World War II, Germany developed an UAV for combat that US post-war programs attempted to eliminate because of its effectiveness. In the 60's, during the Vietnam War, the UAVs were used for stealth surveillance. Due to the success of the previous projects, other countries began to develop UAV systems. But they were mostly for military applications. Therefore, after the 90's, because of the constant criticism of their use in military applications, UAVs played a new role in Earth monitoring. Recently, many new roles in civilian and commercial applications have been proposed [1].

The transmission medium for UAVs is radio frequency and microwave spectrum, since optical spectrum is not practical in some applications. An UAV needs an operator control on the ground, and a network of UAVs uses a protocol for communication. There are many research works in designing communication protocols that allow a group of UAVs to be not only completely autonomous, but also cooperative [2].

This article presents some networking protocols for UAVs, and it is organized as follows. Section II presents some general characteristics of UAVs. In Section III, some networking protocols for UAVs are described. Section IV presents an analysis of the works described in Section III. Section V presents some drone technologies and Section VI concludes our paper.

## II. GENERAL CHARACTERISTICS OF UAVS

UAVs usually use ISM 2.4 GHz band to transmit information to other aircrafts or to the base station (BS). They are equipped with various sensors such as accelerometer and gyroscope for flight control and GPS for location information.

The characteristics of a network of UAVs are very similar to a MANET (Mobile Ad-Hoc Networks). FANET (Flying Ad-Hoc Network) is a special class of MANET/VANET (Vehicular MANET), where the aircrafts have an Ad-Hoc network [3]. Figure 1 shows this classification.

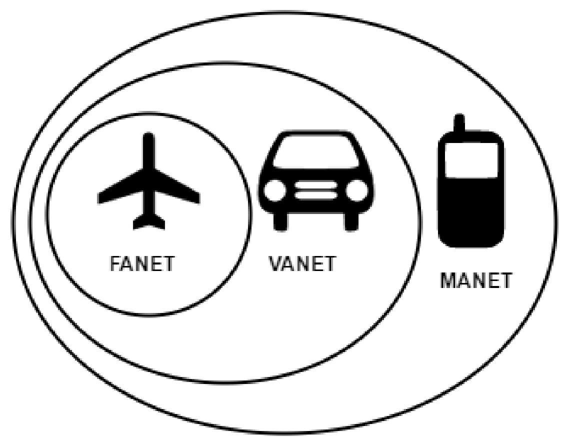


Figure 1. FANETs, VANETs and MANETs

Main characteristics of FANETs compared to MANETs are presented in Table 1 [3, 4].

TABLE I
FANETs vs MANETs

| Characteristic | FANET | MANET |
|---|---|---|
| Mobility | Fast: 30 – 460 km/h and some movement pattern | Slow: 5 – 10 km/h and arbitrary movement |
| Node density | Sparse and few nodes | Similar to FANETs but less sparse |
| Topology change | Fast | Slow |
| Propagation model | LoS (Line of Sight) in most cases | LoS is not feasible some times |
| Computational power | High | Medium |

| | | |
|---|---|---|
| Power consumption awareness | Needed only when the network uses mini UAV | Always needed |
| Localization | GPS | GPS |

As mentioned before, in the early 1900´s the UAVs have their principal use in military applications. Currently the civilian applications have been increasing. Some examples are pipelines and power line inspection and surveillance, oil and natural gas search, and fire prevention [4]. Even more, the use of networks of UAVs in various missions has been widely studied lately. Using a network of UAVs brings more capabilities and more coverage to the mission.

UAVs have been used in various applications such as surveillance and monitoring. Integration with other technologies improves application performance and could make it autonomous. The authors of article [2] have installed a sensor (Fleck 3) that senses temperature, humidity, soil moisture. The UAV is equipped with accelerometer, gyroscope and magnetometer and it is programmable. In this way it is possible to preload rules on the aircraft, allowing the UAV to take decisions and collaborate with other UAVs.

## III. NETWORKING PROTOCOLS

Most of the networking protocols have been developed for military use. UAVs are mainly equipped with omnidirectional antennas, but directional antennas can also be used to increase the transceiver gain at the cost of designing a mechanism to control the direction of the antenna.

### *A. Architectures*

Article [6] presents four architectures for teams of UAVs. All the architectures assume a Base Station (BS) ground node and if the network is homogeneous then all UAVs have the same speed and the same flight pattern. The first architecture is the **centralized architecture**, where the UAVs cannot communicate to each other, only directly with the BS. The three other architectures are decentralized. In the **UAV Ad-Hoc Network** presented in Figure 2, one vehicle is the gateway that sends data to the BS. The gateway has two radios (two antennas), one for communicating with other vehicles and one for connecting to the BS.

**Multigroup UAV Network** is a combination of Ad-Hoc and centralized communication. Lastly, **multilayer UAV Network** is used for heterogeneous UAVs. The lower layer is used for communication between vehicles and the upper layer is used for the communication between gateways and between gateways and BS. The authors [6] conclude that Ad-Hoc Network is the best architecture for a homogeneous team of UAVs, while multilayer UAV Network is more suitable for multiple groups of heterogeneous UAVs (see Figure 3).

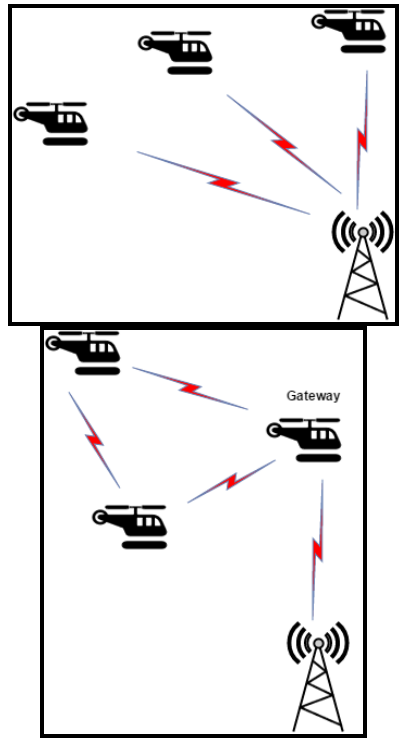


Figure 2. Centralized and decentralized (Ad-Hoc) arquitectures

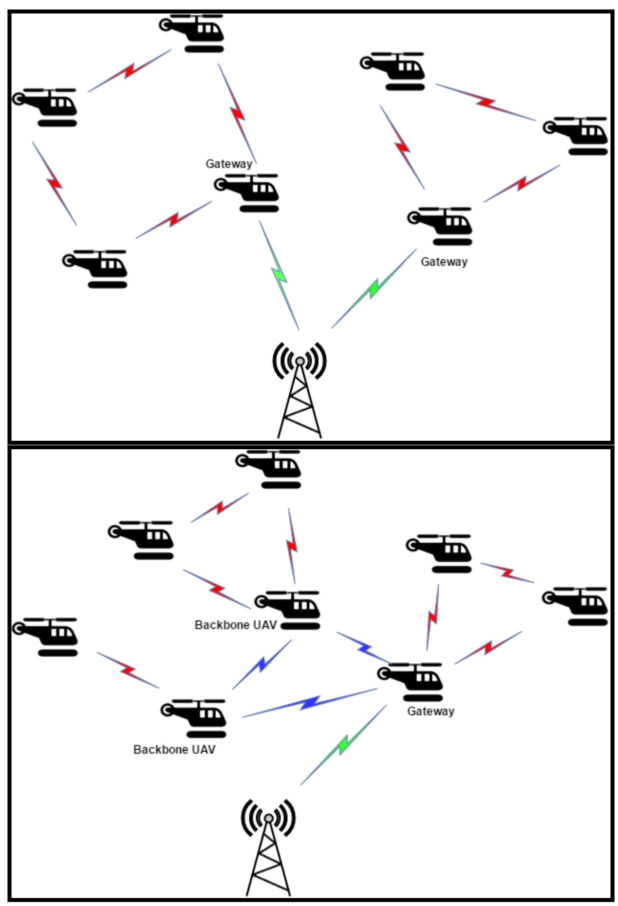


Figure 3. Multigroup and multilayer arquitecture

Paper [7] presents an Opportunistic Resource Utilization Network (Oppnet). The project uses a UAV as a seed Oppnet that has a list of possible helpers. It can also start discovering other helpers that are within its scope. The mission of the UAV is to monitor an area for illegal boats. The UAV then can order or invite the helper to join the mission. The most important characteristic is that the network can grow thanks to the discovery phase. Figure 4 shows a simulation scenario for an extended Oppnet.

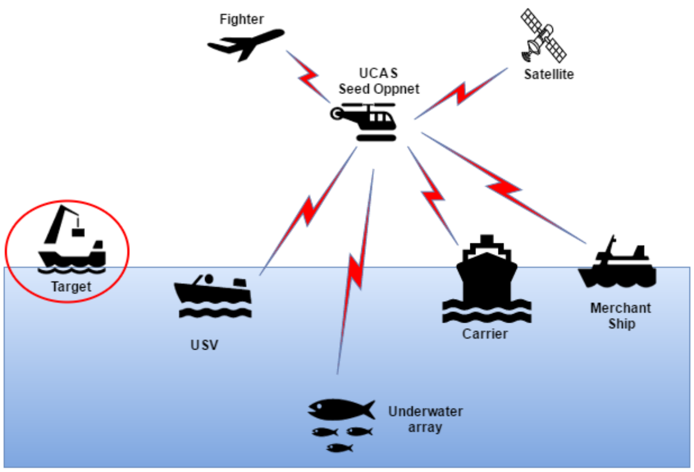


Figure 4. Extended Oppnet scenario

In this scenario a carrier and some combat ships are in a dangerous area. A UAV (UCAS in Figure 4) is in charge of monitoring the area for suspicious boats. The UAV is the seed and starts recruiting helpers. First, it recruits an acoustic array (helper 1). This array finds a suspicious boat (target) and alerts the UAV. The UCAS cannot determine if the boat is illegal or not because it is not within its scope, so it recruits two additional helpers which are some merchandise ships with sophisticated radars that are near the target (helper 2 and 3). Images are sent to LCSs (helper 4) and then to satellites (helper 5 and 6) that process the images and notify the UAV that the watercraft target is dangerous. Finally the UCAS sends a Hornet strike fighter (helper 7) and three unmanned surface vehicles (helpers 8, 9, and 10) to intercept the target. The authors use simulations to measure the performance of the network, such as the time and rate of success intercepting the target with and without using helpers. They also compared the use of invasive (obliged) and less invasive (invited) helpers. The simulations conclude that the use of Oppnet improve (decrease) the time to find and intercept illegal watercrafts and the percentage of success is increased. In addition, the use of invasive helpers has a better performance than using invited helpers.

### *B. MANETs protocols*

Since FANETs is a subclass of MANETs, most of the routing protocols used for MANETs can be used in UAV networks [3, 4].

- **Static routing protocols**: each UAV has a routing table that is not updated during the mission. This is only useful when the topology on the network does not change, for example in a cluster with few nodes.

- **Proactive protocols**: in this case the routing tables are updated when paths are broken. Due to the high velocity and high topology change, this type of protocol is not suitable for UAV networks. Some authors have adapted proactive protocols to better fit UAV networks. Authors of paper [8] present a protocol based on Optimized Link State Routing [9] that uses directional antennas to transmit information to 2-hops neighbors.

- **Reactive protocols**: In this case the route is discovered on demand, thus it has a larger delay. Article [10] presents a time slotted version of AODV [11], where each UAV sends data in a dedicated time slot, similar to ALOHA.

### *C. Location and Geographical-based Protocols*

Paper [12] presents a communication protocol based on location. The communication scheme has one UAV and some nodes on the ground. In each time slot (5 seconds), the UAV has to decide if it transmits data and with whom it communicates. Based on the GPS and RSSI (Received signal strength indication), an UAV determines the distance to the nearest node, the signal power needed to communicate with the node, and it estimates the quality of the channel.

If the signal strength is sufficient, then the UAV sends an ACK to start communication (Figure 5).

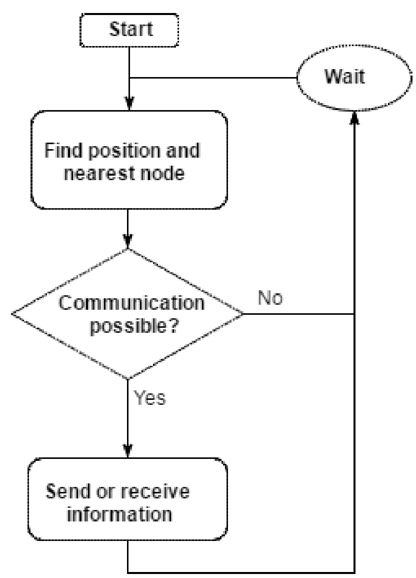


Figure 5. Flow chart of protocol

The authors perform a test with four Waspmotes and one mobile node (the UAV). The map of the site was pre-charged in the UAV. The authors conclude that their protocol save aircraft energy.

Author of [13] uses geographical position to communicate. Two approaches to autonomous UAV control are proposed, leader-follower and swarming. In the first approach, there is a leader and the followers execute an autonomous flight, but they try to imitate the leader. In the second approach, the UAV swarms are distributed and use multi-hop routing. Aircrafts select waypoints and travel through a series of rectilinear moves. All aircrafts travel at the same speed (25 m/s), and waypoint decisions occur periodically. When an UAV reaches a waypoint, it chooses another point using a shared global state and some rules (Distance Rule: select the closest cell; Neighbor Rule: select the cell farthest away from known neighbors; Travel Straight Rule: select the next cell that requires the least direction change to the current flight; Random Rule: select a random cell; Number of Searches Rule: select the cell with the least known number of searches). Each rule either reduces the set of candidate cells to a single, best candidate or selects a random cell using the Random Rule. If several UAVs select the same waypoint, a conflict occurs. Each UAV sends the selected next point to its neighbors so that they can determine conflicts. If there is a conflict, the UAV closer to the waypoint wins and reserves that point. The Greedy Perimeter Stateless Routing (GPSR) [14] is used for communication between UAVs and to communicate to the BS. Authors analyze the performance of the proposed mechanism using OPNET simulations with 13, 25 and 38 UAVs where aircrafts solve the waypoint conflict using the aforementioned rules.

For layered networks, a global routing protocol is ideal. Paper [15] presents an adaptation of the DREAM protocol [16] call DREAM-based graph Protocol that has a location service, a local database, and a routing agent. The location service provides information updates of the position of each node. Location is computed using the distance effect given by the difference in the velocities of two nodes. Similar to the Doppler effect, nodes that are close to some observer seem to be faster than those that are farther away. The local database stores information about nodes that do not vary in time, such as mission data, power settings, gain of the antennas, and frequencies used. Using the routing table with information about UAVs and network layer, the routing agent creates a graph of the network and computes an optimal route to the destination using Dijkstra's algorithm. The layers are determined by the number of WiFi channels in the network. The decision of the route is a power aware approach where power transmission cost is the cost for each edge in the Dijkstra algorithm. The author only presents the idea of the entire simulation, and plans to implement it in future works.

### *D. MAC Layer Protocols*

In paper [17] authors propose a MAC layer protocol. Directional antennas are used at the top and bottom of the aircraft. The UAV senses the medium to determine if there is any ongoing communication. If the medium is empty, then the UAV can transmit data. If it is busy, then the UAV enables a back-off timer, similar to CSMA. Sensing can be done at the physical layer or virtual. Virtual sensing uses a network allocator vector which is a logical abstraction that limits the need for physical carrier-sensing at the air interface in order to save power. The protocol is illustrated in Figure 6.

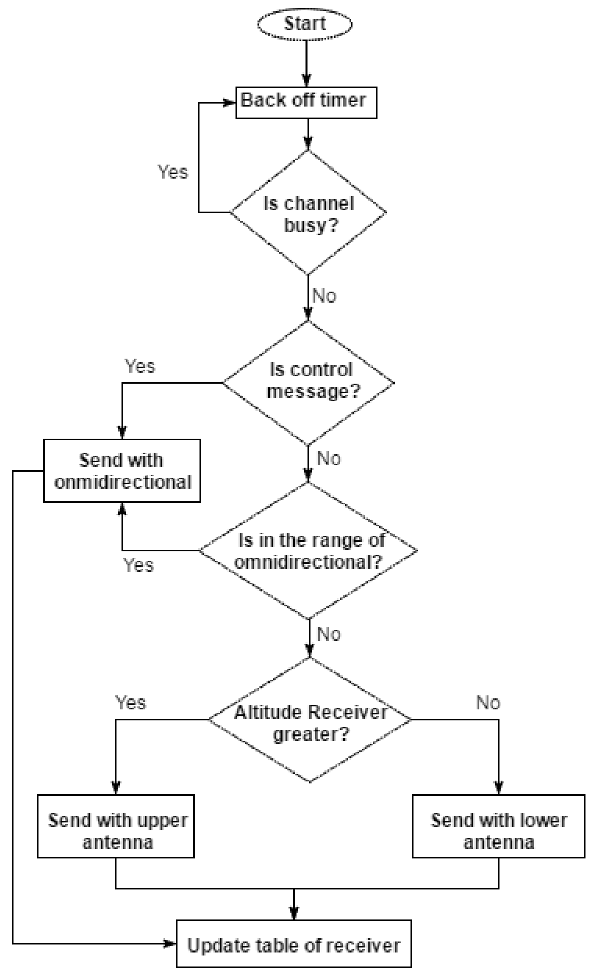

Figure 6. Flow chart

- The RTS/CTS message sequence is used to address the hidden terminal problem.
- If the message is a control message (such as a Hello message), then the sender node uses physical carrier sensing.
- If the channel is empty, then the sender does a virtual sensing to determine if the channel is reserved.

- If the channel is empty, then send an omnidirectional packet with the location and orientation and start the back off timer.
- When the receiver node receives RTS, it senses the medium and if empty then it sends a CTS with its location and orientation and updates its table.

The MAC protocol of the sender node checks the distance between UAVs and if it is within the range of its omnidirectional antennas, the aircraft will attempt communication. If the distance is not within the range, then it checks the altitude of the node 2 (the receiver). If the altitude of node 2 is smaller, then it uses the antenna located at the bottom of the aircraft. Otherwise it uses the upper antenna. After node 2 receives the data messages, it sends an ACK (acknowledgement) control message. If the packet does not reach the node 2, then a retransmission is attempted.

Starting with the 5th retransmission, they are done using the omnidirectional antenna. After the 7th retransmission, data are discarded. Using directional antennas avoids flooding the network, since messages are transmitted only to the intended receivers. In addition, using directional antennas increases the communication range. Authors use OPNET simulator to perform simulations and compare the performance of this protocol with IEEE 802.11 for various metrics such as SNR, BER, end-to-end delay, and throughput.

### *E. Shortest-path based Protocols*

Similar to MANETs, UAV networks need to have a reliable communication among the nodes. One way to ensure that is trying to transmit the information in a channel with low BER and high SNR. Many applications wish to transmit the information as soon as possible. Using an adaptation of shortest path based routing protocols can help to achieve this objective.

Paper [18] presents an adaptation of AODV that uses the Dijkstra algorithm to calculate the routes between aircrafts. The authors use a team of UAVs for several tasks, such as transmitting a video to a Base Station (BS). The source node starts by sending a route request to the neighbors. When nodes receive the message, they rebroadcast and calculate a cost based on the inverse of the Shannon's capacity. The route is then based on the hops that make the lowest cost in the computation, this is the route with the better data rate. The nodes also use the concept of agents to distribute the tasks in the mission. For this the authors use the Consensus Based Bundle Algorithm (CBBA) [19] that runs on the BS, where the nodes bid the task according to their capabilities. Agents receive rewards when they complete tasks and then the mission. The authors perform simulations where the number of nodes varies between 2 and 10. The nodes must gather information about the area. If the UAVs collect information from farther places, then they get more rewards. One scenario with three different conditions was used: nodes with connectivity, nodes with connectivity and good data rate, and nodes with connectivity, good data rate and good BER. It was concluded that the success of the tasks depends on the connectivity between nodes.

UAVs networks can also be used as a support for other networks, such as wireless sensor networks. Authors of [20] use a team of UAVs as backbone of a sensor network that has isolated islands of sensors (Figure 7).

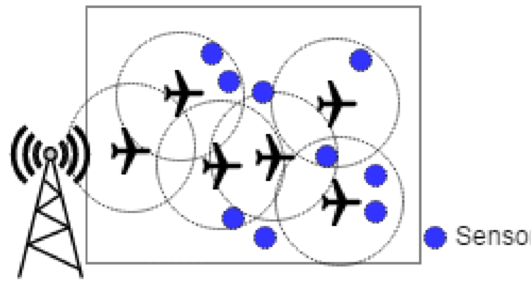


Figure 7. Scenario of the network

The UAVs act as a relay network to the sensors. The BS sends beacons to the closer UAV, and then this aircraft rebroadcasts the information, flooding the network. Each node that broadcasts the information adds to the beacon its own ID, so the receiver UAV can update its neighbor table and the distance in hops, similar to the DSDV protocol. If an UAV receives beacons form more than one neighbor, then it can construct more than 1 route to reach the BS. The UAVs fly in a random pattern, but they maintain connectivity with the neighbors of the path to the BS. If an aircraft flies and notices that the path is broken, then it makes a decision to fly near the neighbors of the path. To keep track of the neighbors on the path to the BS, the UAV uses the Signal Strength (RSSI) to move towards the neighbor with highest signal and to not disconnect from the network. The authors use the GrubiX simulator to probe the protocol. They compare a random fly with their protocol, and measure the connection rate and the dispersion of the network. Authors show that using this protocol the entire WSN is connected, and they measure the number of neighbors (sensors and UAV) of each sensor.

### *F. On-Demand Protocols*

Since UAV networks are a subset of the MANETs, using on demand protocols seems a good choice. The authors of [21] present a project called Ad-Hoc UAV Ground Network. The aircrafts are flexible with different flight configurations and have a multi-hour endurance. The Ad-Hoc network performance depends on many factors such as the quality of the channel, the number of hops, fixed or mobile BS among others. In this project, the author uses the Dynamic Source Routing (DSR) protocol for communication with other nodes. The communication is between UAVs and the BS on the ground. Authors choose DSR, an on-demand protocol where a node needs to know the path to the destination only when it has data to send. In this way, nodes do not waste bandwidth and energy trying to know all the routes that maybe they will never use. When an UAV needs to send a packet, it initiates the route request between the nodes. DSR also uses source routing where an UAV source specifies which route the packet will follow.

Each UAV creates a report periodically that has the information and also the node position. This report is sent to the gateway that sends it to the BS. The project compares two scenarios. In the first, an Ad-Hoc network of ground nodes is disconnected because of the distance between them, so the UAV acts as a bridge. In the second scenario, an Ad-Hoc network of UAVs was used, so the communication range of a ground node was incremented. As a result, it was noted that the performance of the network using UAVs was better in terms of throughput, number of hops in the path, and number of messages received vs messages sent.

## IV. ANALYSIS OF THE WORKS

Table 2 presents an analysis of the advantages and disadvantages of the works presented in this paper.

TABLE II
Analysis of the works

| Work | Advantages | Disadvantages |
|---|---|---|
| **Oppnet [7]** | The network is very useful in military missions. The use of helpers and possibility to invite new helpers to be part of the network lead to a network which is flexible, reconfigurable and with growing capabilities. The security is the helpers is not compromised. | The success of the mission depends on the delay in inviting helpers to join the mission. If the delay is too long then there is the possibility that the target will run out the area and cannot be intercepted. |
| **Position apriori [12]** | The mechanism was tested in real life, and performance was as expected by the authors. | There is no comparison with other protocols. |
| **Geo routing [13]** | The author tries to give the UAVs the notion of intelligence so they can make decisions based on some rules. The work is useful in military missions and for searching because of the flexibility. GPSR improves Average Direction Changes versus broadcast. | The author does not see the effect of the history packet frequency. |
| **Adaptation of DREAM [15]** | The authors use the concept of agents to give the network a dash of intelligence in taking decisions. The initial configuration on the network permits the autonomous work of the network without human control. The nodes do handshake so the control station can be aware of the presence of all the nodes. | The authors does not make simulations to measure the effectiveness of its framework. The work could include the history of movement to predict future movements on the network that could be helpful to the performance of the protocol. |
| **MAC Based [17]** | The use of directional antennas extends the operating range and helps avoiding collisions. The mechanism is based on CSMA which is a well-known protocol. The mechanism outperforms IEEE 802.11 in the SNR, BER, end-to-end delay, traffic and throughput. | The use of omnidirectional antennas could lead to collisions in the network. |
| **Adaptation of AODV [18]** | A real outdoor experiment was performed with three UAVs that demonstrate the results obtained in the simulations. The algorithm uses task assignment distribution to plan the missions and the topology of the network, so that the UAVs are able to perform complex tasks. The reward concept was introduced, which is usually used with agents. | To have a more accurate data rate and BER in the simulations, other parameters of the environment must be accounted for in future works. |
| **Relay network [20]** | The proposed mechanism integrates two different technologies to improve the performance of the networks | The author measures insufficient metrics to conclude the efficiency of the protocol. |
| **AugNet [21]** | The authors made a test bed to prove the efficacy of their network. The network with UAVs has a better performance that without UAVs. Using UAVs can help reach sites such as BSs, which nodes on the ground cannot reach otherwise. Also the use of UAVs can lead to routes with better throughput and | The authors use the DSR protocol that can have a large overhead since the path is included in data messages (source routing protocol). The author can choose another on demand protocol that do not have that problem. |

| | | |
|---|---|---|
| | shorter distance. | |

## V. Technologies Available

There are many applications that use drones. Gyrodine developed several UAVs between 1949 and 1969, which flew until 2006. They designed many UAVs for U.S. Navy, such as the Drone Anti-Submarine Helicopter DASH. These UAVs were designed to deliver torpedoes or nuclear charges [22]. The black Hornet is a nano-UAV, which weighs only 15 grams. This drone developed by Prox Dynamics for military applications is expected to be used for both indoor and outdoor operations [23]. Global Hawk is a 44 foot long UAV acquired by NASA and used for the Earth Science Project Office. It has an endurance of 24 hours, it uses Ku band, 2 Mbps and it flies over 65,000 feet for measurements of the atmosphere, monitoring and observing remote locations [24].

Some other applications of drones are delivering products to customers, aiding to provide Internet services by Facebook in multiples zones of the world, News and Photography, monitoring of the agriculture, monitoring animal population growth, and public services such as search and rescue. Amazon and Walmart are starting their trails to deliver packages to clients using drones [25, 26]. Paper [27] describes a mobile ambulance using drones and many other military applications are presented in [28].

There is a wide portfolio of drones on the market, starting from 20 dollars to 31,000 dollars. The price varies with the size and characteristics of the drone. During the last five years, companies such as DJI [29], Parrot [30], and 3DR [31] have commercialized drone kits at low cost that allow users to program drones and test different communication protocols.

For example, DJI [29] offers Matrice100 - a quadcopter that can be fully programmable and tested for various applications. The user can develop applications using Windows, Linux, or other embedded systems. Parrot [30] offers the Skycontroller device with an Android Application called FreeFlight. The application is open source, allowing users to develop their own functionalities for the drone.

## VI. Conclusions

Some conclusions of the works presented in this paper are stated as follows.

There is a lot of work in the area of networking in UAVs which also extends to the Autonomous Underwater vehicles. The use of agents in the UAVs allows the network to have some kind of intelligence that could be helpful in the decision making in the missions.

When the UAV network is Ad-Hoc, it is known as FANET, a subset of the MANET. This characteristic allows the possibility to use communication and routing protocols from MANETs. Similar to MANETs, the most suitable type of protocols are on-demand or location based protocols, because of the fast topology change and the big probability of disruptions.

One good alternative for investigation in future works is using the concept of DTN (Delay Tolerant Network) with UAV networks, since UAV networks could have disruptions due to high mobility. UAVs have been used together with other types of networks, such as Wireless Sensor Networks. UAVs form a relay network that can be used by sensor nodes that are too far from the BS or are isolated from other nodes.

More real life experiments must be performed to prove the efficiency of the protocols presented in this paper. Nevertheless UAV networks are a great asset already used by many important applications.

## VII. References


[1] NOVA, Time line of UAV. (Online): http://www.pbs.org/wgbh/nova/spiesfly/uavs.html

[2] S. Teh, L. Mejias, P. Corke and W. Hu, "Experiments in Integrating Autonomous Uninhabited Aerial Vehicles (UAVs) and Wireless Sensor Networks". Australasian Conference on Robotics and Automation (ACRA 08). 2008.

[3] H. Tareque, S. Hossain and M. Atiquzzaman, "On the Routing in Flying Ad hoc Networks". Federated Conference on Computer Science and Information Systems. 2015.

[4] I. Bekmezci, O. K. Sahingoz and S. Temel, "Flying Ad-Hoc Networks (FANET): A survey". Ad-Hoc Networks, 2013.

[5] B. B. Wongui, "Morphing Unmanned Aerial Vehicles". Master's Thesis. Aalto University. 2010.

[6] J. Li, Y. Zhou and L. Lamont, "Communication architectures and protocols for networking Unmanned Aerial Vehicles". Globecom 2013 Workshop – Wireless Networking and Control for Unmanned Autonomous Vehicles. 2013.

[7] L. T. Lilien, L. B. Othmane, P. Angin , A. DeCarlo, R. M. Salih and B. Bhargava "A simulation study of ad hoc networking of UAVs with opportunistic resource utilization networks". Journal of Network and Computer Applications. 2013.

[8] A. Alshabtat, L. Dong, J. Li, and F. Yang, "Low latency routing algorithm for unmanned aerial vehicles ad-hoc networks". International Journal of Electrical and Computer Engineering, 2010.

[9] T. Clausen and P. Jacquet, "Optimized link state routing protocol (OLSR)," RFC 3626 (Experimental), October 2003.

[10] J. Forsmann, R. Hiromoto, and J. Svoboda, "A time-slotted on-demand routing protocol for mobile ad-hoc unmanned vehicle systems". SPIE 6561, 2007.

[11] C. E. Perkins and E. M. Royer, "Ad hoc On Demand Distance Vector Routing". EITF, 2003.

[12] L. Sboui and A. Rabah, "Optimized UAV Communication Protocol based on Prior Locations". Mechatronics and intelligent Systems, May 2012.

[13] R. L. Lidowski, "A novel communications protocol using geographic routing for swarming UAVs performing a search mission". Thesis. Air University, Ohio. 2008.

[14] B. Karp and H. T. Kung, "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks". MobiCom, 2000.

[15] H. C. Christmann, "Self-configuring ad-hoc networks for unmanned Aerial systems". Master Thesis. Georgia Institute of Technology. 2008.

[16] B. Stefano, C. Imrich, R. S. Violet, and A. W. Barry, "A distance routing effect algorithm for mobility (dream)," in Proceedings on the 4th annual ACM/IEEE international conference on Mobile computing and networking. 1998.

[17] A. Ilah Alshbatat and L. Dong, "Adaptative MAC protocol for UAV communication Networks using Directional Antennas". International Conference on Networking, Sensing and Control (ICNSC), IEEE, 2010.

[18] A. Kopeikin, S. S. Ponda, L. B. Johnson, and J. P. How, "Multi-UAV Network Control through Dynamic Task Allocation: Ensuring Data-Rate and Bit-Error-Rate Support". Globecom Workshops 2012 IEEE.
[19] A. N. Kopeikin, S. S. Ponda, H.-L. Choi, and J. P. How, "Real-Time Dynamic Planning to Maintain Network Connectivity in a Team of Heterogeneous Unmanned Systems". International Workshop on Wireless Networking for Unmanned Autonomous Vehicles at the IEEE GlobeComm Conference, 2011.
[20] E. Pignaton de Freitas, T. Heimfarth, A. Morado Ferreira, I. F. Netto, F. R. Wagner, T. Larsson, C. E. Lino and C. E. Pereira, "UAV Relay Network to Support WSN Connectivity". International Congress on Ultra-Modern Telecommunications and Control Systems and Workshops (ICUMT), 2010.
[21] T. X. Brown, B. Argrow, C. Dixon, S. Doshi, R. G. Thekkekunnel and D. Henkel, "AD Hoc UAV Ground Network (AUGNet)". American Institute of Aeronautics and Astronautics. 2004.
[22] Gyrodine. (Online): http://www.gyrodynehelicopters.com/qh-50_evolution.htm
[23] Robert L. Lidowski, "A novel communications protocol using geographic routing for swarming UAVs performing a search mission". Thesis. Air University, Ohio. 2008.
[24] Global Hawk, (Online): http://www.nasa.gov/centers/armstrong/aircraft/GlobalHawk/index.html
[25] Amazon testing drone delivery, (Online): https://www.youtube.com/watch?v=Le46ERPMlWU
[26] Reuters, "Exclusive: Wal-Mart seeks to test drones for home delivery, pickup", (Online): http://www.reuters.com/article/us-wal-mart-stores-drones-exclusive-idUSKCN0SK2IQ20151027
[27] TU Delft - Ambulance Drone (Online): https://www.youtube.com/watch?v=y-rEI4bezWc
[28] Power of Drones - Totally Cool Uses for Drones | BEST DRONES FOR 2015, (Online): https://www.youtube.com/watch?v=3zE6BaFDkP4
[29] DJI Developer, (Online): developer.dji.com/onboard-sdk/. (26 May 2016)
[30] Parrot, (Online): http://www.parrot.com/usa/. (26 May 2016)
[31] 3DR, (Online): https://3dr.com/enterprise/. (26 May 2016)