Unmanned Aerial Systems: Overview and Open Challenges

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***Abstract*—Unmanned Aerial Systems (UAS) are attracting increasing attention since their introduction in many civil fields and after being solely dedicated to military applications. An UAS is composed of Unmanned Aerial Vehicles (UAV), ground stations and data links. UAVs may form a Flying Ad Hoc Network (FANET), they can communicate with each other or with the ground infrastructure to deliver and exchange information. UAV network topology has a direct impact on the communication scheme, which can be centralized or decentralized. Trajectory and speed variation of UAVs are represented by mobility models. UAVs can move individually or within a group. To meet the requirements of an UAS, which are ensuring high coverage and high speed, new wireless data links are being developed while taking into account the frequency spectrum availability.**

In this paper we briefly present the general characteristics of UAS, UAV and FANET. We present UAV different current applications, and then we discuss features of their topologies. Next we investigate the different UAV mobility models applied to individuals and to groups. Finally, we present a review of the most important communication protocols proposed for UAS.

Keywords—UAS, UAVs, FANET, topology, mobilty models, data links.

I. INTRODUCTION

Drones or Unmanned Aerial Vehicle (UAV) or Remotely Piloted Aircraft (RPA) are small air planes without a pilot onboard, they can be remote controlled or autonomous.

First they were used during wars, for military purpose and for security reasons. The payload of the UCAV (Unmanned Combat Aerial Vehicle) is usually a weapon. Now they are used especially for civil applications such as filmmaking, television, agriculture, environment, search and rescue, air quality monitoring, crime scene investigation, disaster response, wildlife tracking and traffic monitoring.[1] And in the near future, a group of autonomous UAVs is expected to execute complex missions in dynamic situations. Introducing communication awareness to the autonomous UAVs, makes possible to react in real-time. So when the channel conditions change and the topology changes, UAVs will be able to detect and avoid obstacle and plan a collision-free path [2][3].

UAVs are part of an UAS (Unmanned Aircraft Systems). An UAS is composed of one or more air carriers, one or more ground stations for control and for collection of detections and radio data links between air carrier and the ground part. The performance and capacity of the UAS is directly related to the abilities of the UAVs because they are responsible for delivering the payload or data to its receivers. UAVs can carry a camera, an infrared camera, a gyroscope and anything on board. The camera is used to transmit on real-time what is happening on the ground, the infrared camera is used to detect heat (human, animal, a fire, a motor, etc) and the gyroscope is used to stabilize the movements of the drone, to improve the tracking of a target or the quality of an image. UAVs can transport things used for rescuing people and even weapon in combat cases. The size and the mass of the UAV depend on the desired capacity; it can go from a few grams to several tons.

UAVs are used in an increasing manner and are indispensable in both military and civilian areas because of their light weight, small size, high flexibility, low price, zero casualties. To execute a mission, using multiple small UAVs is better than using a large one, since small UAVs are relatively cheaper than large ones and they fly longer period. Also the cooperation of multiple UAVs is preferred to improve the overall operational efficiency since a single UAV have limited energy, short transmission range, and simple functions.

Therefore, the solution is to build an UAV network; Flying Ad Hoc Networks (FANET). UAVs usually work in complex and changing environment with flexible operational manners and high mobility, therefore, it is necessary to apply the architecture of Mobile Ad Hoc Network (MANET) in the design of UAV network. Setting up a mobile UAV network not only extends operational scope and range but also enables quick and reliable response time. Also setting up a mobile UAV network is better in terms of connectivity, routing process, services, applications, etc.

Studies are trying to improve the traditional MANET to satisfy the requirements of UAVs. There are several routing algorithms in MANET, and most of them are not directly applicable for the FANET due to the UAV specific issues, like quick changes in link quality. While MANET nodes move on a certain field, VANET (Vehicular Ad Hoc Network) nodes move on the highways, and FANET nodes fly in the sky. The mobility degree of FANET nodes is much higher than the mobility degree of MANET or VANET nodes. Because of the high mobility of FANET nodes, the topology changes are more frequently than in a typical MANET or even VANET. FANET also needs peer-to-peer connections for coordination and collaboration of UAVs. It also collects data from the environment and relays to the command control centre, as in wireless sensor networks. Typical distances between FANET nodes are much longer than in the MANETs and VANETs. In order to establish communication links between UAVs, the communication range must also be longer than in the MANETs and VANETs. This phenomenon affects the radio links, hardware circuits and physical layer behaviour. The communication requirements of UAVs differs significantly from traditional networking assumptions, MANET and VANET in terms of connectivity, data delivery, latency and service [4].

The rest of this paper is organized as follows. In section II, we present various UAV applications. In section III, we present the different existent UAV topologies. In section IV same mobility models will be described. Communication protocols are provided in Section V. In section VI, we discus some research challenges. Finally, in section VII, we conclude.

II. UAV APPLICATIONS

First UAVs were deployed exclusively in military applications. In deed the innovation in UAV for military and special operation applications started in the early 1900s, the development continued during World War I and even until now. In the 21st century, technology reached a point of sophistication, so the UAVs are now being used in an increasable manner for civil applications such as entrainment, environment, agriculture and disaster management.
UAVs should be able to perform both indoor and outdoor missions.

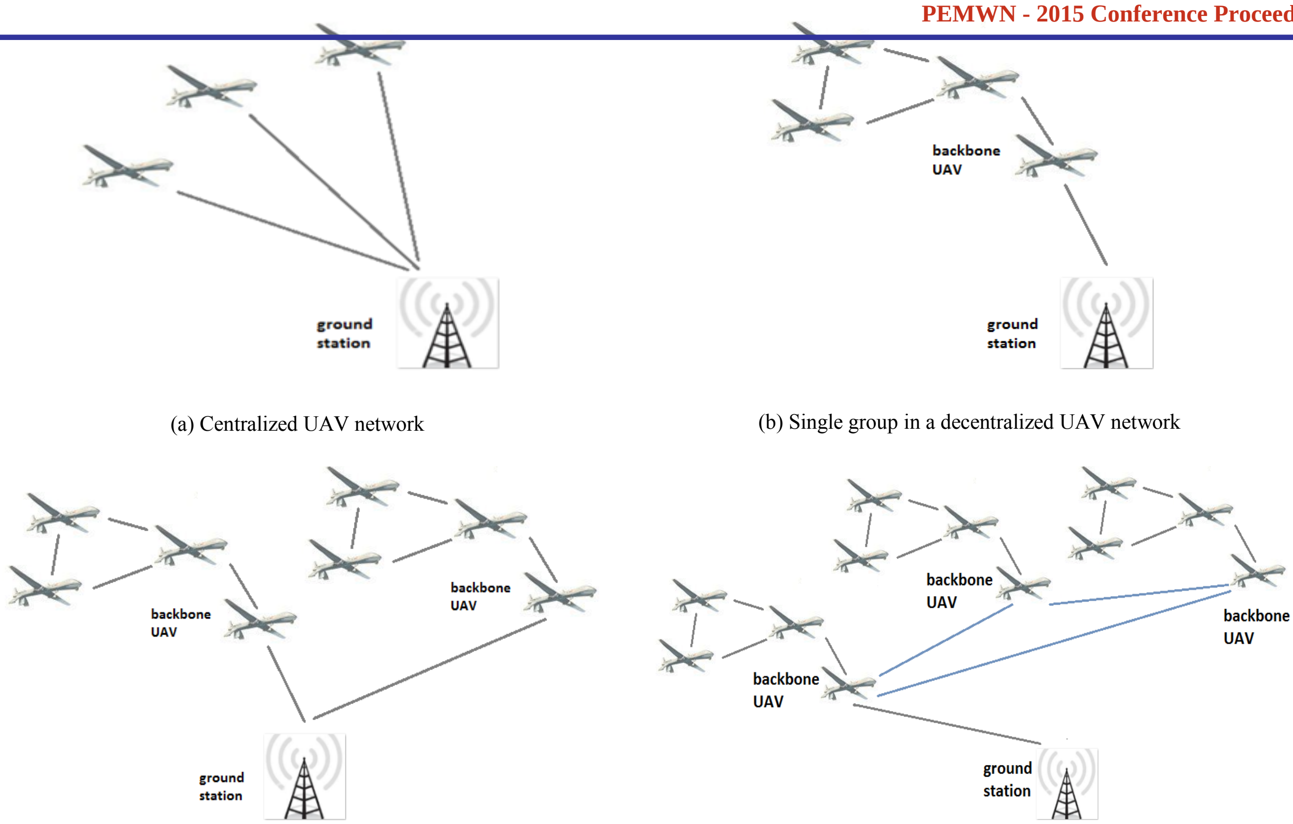
UAVs can be used in the context of natural disasters [5]. When a natural disaster occurs in a populated zone, a fast and effective organization of the disaster management is necessary. Because, at any time, the rescue teams need immediate and relevant information concerning the situations they have to face and the assistant they have to bring. The UAVs must be autonomous and able to provide environment and people information. The live saving tasks are environment identification (reconstruction of the environment using a camera and then navigation according to the reconstruction) and people identification (estimate the number, composition, direction and velocity of peoples by using detectors).

UAVs are used for disease management. In this context the MedizDroid project developed UAV multicopter drones for mosquito vector control and suppression. Mosquitoes are vectors for the transmission of several infectious diseases such as malaria. The UAV multicopter drone based solutions are being investigated as replacements for expensive aerial spraying, ground vehicle spraying, and backpack spraying for mosquito vector control. This solution prevents also the exposure of human to diseases. UAV multicopter drones will support precision spraying, in fact the dimension of the area to be sprayed will be defined and then the amount of insecticide to use will be fixed [6].

Another field of UAV application is tracking a moving target with variable speed [7]. For that tracking task, the proposed solution uses fixed-wing UAV which generates an optimal path according to the relative position, the orientations, the speed ratio and the minimal turning radius. This proposed algorithm aims to synchronize the UAV and the target motion, to minimize the UAV and the target distance and to make sure that the moving target never escapes from the sensor coverage region of the UAV.

UAVs can be used to prevent a moving ground target from accessing to a protected zone [8]. This UAV mission is included in the security field. So to help the UAVs achieving this task, Unattended Ground Sensors (UGSs) which are placed in the road network are triggered when an intruder passes by (a trigged UGS means it is turning from red to green and recording the intruder's time of passage). The UAV's objective is to guarantee capture of the intruder (on camera) before he reaches the protected zone. For capture to occur, the intruder and UAV have to be at the same location at the same time. To make this happen the UAV must take a decision; moving or staying in the neighborhood of the UGS location while taking into account the positions information of the intruder (stored information are uploaded to the UAVs when they pass by the UGSs).

Agriculture is another field of UAV application. The proposed application aims to reduce the involvement of human to preserve their health and to get more accuracy in the operations [9]. For example UAV can be utilized for spraying pesticide on a crop field while communicating with a Wireless Sensor Network (WSN). In the proposed methodology (based on Particle Swarm Optimization) the UAV corrects its route based on feedbacks sent by the WSN. The feedbacks can be about the weather conditions (speed and direction of the wind) and how the spraying is falling in the crop field (concentration of the sprayed pesticides). The optimization of "route changing parameter" is essential to ensure a precise spraying. In fact when the UAV goes from an area to another, it gets the new weather condition from the WSN, it sends the collected information to the base station which calculates the optimized "route changing parameter" and then sends it back to the UAV.



(a) Centralized UAV network

(b) Single group in a decentralized UAV network

(c) Multiple groups in a decentralized UAV network

(d) Mutiple layers in a decentralized UAV network

Fig.1. UAV topologies

UAVs can be also used for the measurement of a crop field surface.

UAVs may be used for entrainment, for example in filmmaking to get better views, in publicity to get a better attention from peoples and in sporting events to get closer to the athletes.

Also UAVs are usually employed in the context of environment; in cities as well as in forests. In cities, UAVs can be involved in air quality monitoring, traffic monitoring and meteorological observation. In forest, UAVs can be involved in fire detection, in illegal hunting detection and in counting wildlife.

III. TOPOLOGIES

The different topologies that can be applied to an UAV network are classified in this section. The communication between UAVs and the base station change according to the topology. A classification was proposed in [10].

A. Centralized Communications

In the centralized UAV communication architecture, presented in Fig. 1(a), there is the ground station as the centre node and UAVs to which they are directly connected. In this network topology, UAVs are directly connected to the ground station but they are not directly connected to each other. The transmission and reception of command and data can only be between an UAV and the centre node, and this centre node is acting as a relay when communications between two UAVs needs to be routed. The consequences of this topology are a short information delay between the ground station and an UAV but a long information delay between two UAVs because of the obligatory transit by the ground station. This communication architecture is not robust because of the unique relay node; when it is damaged no more information can be routed. Also this architecture is not suited for medium and small UAVs because the required high transmission power is not practical for them.

B. Decentralized Communications

Many decentralized communication architectures exist, but there are common characteristics such as; no central node is required, the relay node can be an UAV and communication between two UAV can be direct or indirect. Here we have the concept of groups. A group is formed by UAVs of similar type and physically close to each others.

1) UAV Ad Hoc Network:

In the topology shown in Fig. 1(b) we have a single group, the member of the group are flying close to each others. The area coverage is better. UAVs in this group will participate in data forwarding and only the gateway UAV is needed to connect to the ground station. The gateway UAV uses one radio for communicating with other UAVs and another for communicating with the ground station.
This ad hoc network architecture is appropriate for a group of similar UAVs and for operations such as persistent surveillance.

2) Multi-Group UAV Network:

Fig. 1(c) illustrates a topology with multiple groups; the members of each group are physically close to each other and have the same type. Each group is considerate as an ad hoc network with a backbone UAV connected to the ground station. In this type of network there is two types of communication; intra-group communications and inter-group communications which involve necessary the backbone UAVs and the ground station.

The Multi-Group UAV Network is appropriate for large number of UAVs with different flight or communication characteristics.

3) Multi-Layer UAV Ad Hoc Network:

The architecture presented in Fig. 1(d) is a multi-layer architecture with multiple groups. It is composed of a lower layer and an upper layer. The lower layer is formed by the groups; the upper layer is formed by the backbone UAVs of all groups. Unlike the multi-group UAV network, only one backbone UAV is directly connected to the ground station.

When exchanging information between two groups, there is no need to pass through the ground station, so the load in the ground station is reduced. This communication architecture is robust because multiple backbone nodes exist, and it supports one-to-many UAV operation mode (this mode involves one operator and multiple UAVs).

C. Groups forming

The clustering process consists of electing a cluster head (CH) and cluster members (CMs). CHs perform the Inter Cluster Routing using long-range transmission, and CMs perform the Intra Cluster Routing using short-range transmission.

To elect the CH a Node-Weight heuristic algorithm can be applied [11]. This consists in assigning weights to UAVs according to the connectivity degree, the relative speed, the residual energy and the equipment. Not all type of UAV can became CH only the lead UAVs because they have more initial energy, less relative mobility, and longer transmission range than task UAVs. Task UAVs can perform reconnaissance, electronic countermeasure and direct attack, while lead UAVs can perform communication coordination and management of the formation.

The lead UAV with the highest weight becomes the CH. In critic situations like in battlefield environment, a backup CH must be selected to take the roles of CH when is not eligible. The backup CH has the second largest weight. Then to select the CMs, the CH broadcasts CH declaration message, while other UAVs in the formation reply to the CH and become CMs.

To get more robust cluster architecture against network topology changes and to speed up in the process of cluster maintenance, each UAV maintains a cluster information table. For the CMs, the information table consists of a Status Table and a Neighbour Table (location information of one-hop neighbour nodes). For CH, the information table consists of a Status Table, CM Table (information of CMs in the cluster), CH Table (location information of all CHs in the network) and Temp Table (information of temporary members in the cluster).

Another proposed clustering scheme may take into account the spectrum heterogeneity, the node degree, the intracluster delay and the stability of topology as well. So a new metric called “node importance degree" was introduced [12]. Initially, each node broadcasts its available channel set, location, speed, best position and mobility characteristics in each available channel. When a node collects all its two-hop neighbours' information, the topology is formed. Then, each node calculates its largest node importance degree. The node with the largest node importance degree is selected as the CH. Or two issues can occur; the selected CH is not being able to connect with other CHs and the assigned channel is occupied by intercluster communication. To solve these two issues the solution is to select a member node with the next largest node importance degree as CH. This new CH must be able to operate on the intercluster control channel and connect with other CHs.

IV. MOBILITY MODELS

The mobility models define trajectories and speed variations of the mobile nodes and represent the evolution of their positions. So the network topology and the communication protocol performance are affected by the nodes mobility since new links can be created and others can be broken. There is two types of mobility models; the entity mobility models and the group mobility models. In the entity mobility model each UAV moves individually and its actions are completely independent from other UAVs. In the group mobility models, UAVs are moving together and working together in a cooperative manner to achieve common goals.

A. Entity mobility model

In this sub section we introduce same mobility models applied to mobile nodes working individually. In the entity mobility model there is random movements and determinist movements (trajectories are predefined).

The Random Walk Mobility Model [13] was developed to mimic the unpredictable movement of entities in nature. It is a memoryless model because it retains no knowledge concerning its past locations and speeds values, so the current values are independent from the past ones and are chosen from a pre-defined range. A mobile node may change its direction and speed after travelling a specific distance instead of a specific time or when it reaches a boundary.

The Random Waypoint Mobility Model [13] is a model that includes pause times when changing direction and/or speed . The mobile node travels toward the randomly chosen destination at the distributed selected speed. When it arrives, it pauses for a specified period of time before starting the process again. In the Random Waypoint Mobility Model, fast mobile nodes and long pause times actually produce a more stable network than a scenario with slower mobile nodes and shorter pause times.

In the Random Direction Mobility Model [13], mobile nodes choose a random direction to travel to it and then travel to the border of the selected area in the chosen direction. Once the mobile node reaches the boundary, it pauses for a specified time before continuing the process. For that it chooses another angular direction (between 0 and 180 degrees). The

Random Direction Mobility Model made end to the problem of clustering in the centre of the area observed when using the Random Waypoint Mobility Model.

The Boundless Simulation Area Mobility Model[13] handles differently the movement of the mobile nodes when they reach an area boundary, so no more sudden direction changing and no more sudden moving stops. In the Boundless Simulation Area Mobility Model, when mobile nodes reach a boundary they continue travelling and reappear on the opposite side of the area.

The Gauss-Markov Mobility Model [13] was designed to adapt to different levels of randomness. Initially each mobile node is assigned a current speed and direction. Then future velocities and directions will be influenced by the past ones. So no more sudden stops and sharp turns like those in the case of Random Walk Mobility Model. Also the Gauss-Markov Mobility Model ensures that mobile nodes don't remain too long near the edge of the area by modifying the direction variable.

Chiang's mobility model [13] is based on probability, it is used to determine the position of a particular mobile node in the next time step. A node may follow north, south, east or west direction and continuing in the same direction has the highest probability. So the current position is essential to pass from the previous position to the next position. This model presents realistic behaviours because it is based on probability rather than on purely random movements. And there is no highly variable direction like in the Random Walk Mobility Model.

In Pararazzi Mobility Model [14] each UAV chooses a movement type and fixes its characteristics (location and speed). There is five possible UAV movements in this model:

- Stay-At: this means that the UAV hovers over a fixed position forming a circular movement
- Way-Point: this means that the UAV follows a straight path to a destination
- Eight: the UAV flies around two fixed position forming a «8» trajectory
- Scan: the UAV performs a scan of a defined area by doing a round-trip trajectories
- Oval: the UAV flies around two fixed position in an oval trajectory

Because of all the possible movements in the Pararazzi Mobility Model, it can be adapted to any type of mission by just changing the probability of the movement.

The «Way-Point» movement is the first movement done by the UAV because it permits to reach the assigned area, then the UAV follows a well-defined path according to the chosen movement. «Stay-At», «Oval», and «Scan» are the most produced movements during a mission flight, while the probability that «Eight» and «Way-Point» occurs is equal to 5%.

In the Distributed Pheromone Repel Mobility Model [15] an UAV can take a decision to turn left, right or go straight ahead to get to areas no recently visited. So as an UAV moves, it marks the areas that it scans on its map. To share this information with the other UAVs, each UAV regularly broadcasts its map and others update the visited area in their maps.

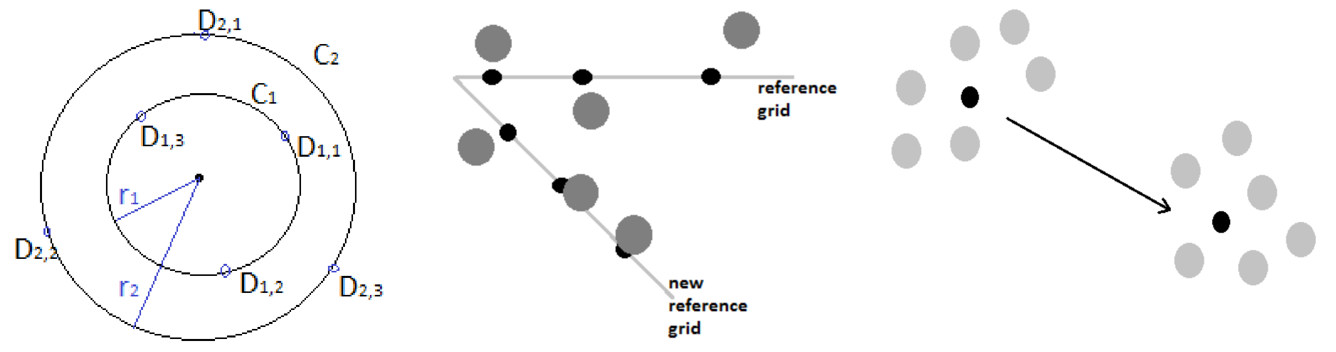
B. Group mobility model

In this sub section, we introduce same mobility models applied to mobile nodes working within a group.

The semi-random circular movement (SRCM) [16] model is suitable when the mission is to gather information. In this model the UAVs are hovering over a specific location in a circular movement. UAVs are assigned with a specific destination according to mission requirements, and then follow a predefined path to reach the destination. In fact when the UAV reaches one of the destinations, which are predefined in the circular path, it pauses for a certain time and then continues its circular path to reach all the other destinations and when it is done the UAV changes its circular path.

From Fig. 2(a) a first circular path of an UAV can be C_1 and the predefined destinations can be $D_{1,1}$, $D_{1,2}$ and $D_{1,3}$. And the circular path C_2 with the radius r_2 can be a second randomly chosen path by the same UAV, or it can be an independent circular path of another UAV. Many UAVs can be involved in scanning sub areas to search and track as many targets as possible.

The UAVs determine their circle path in an autonomous manner, so they are able to detect and avoid the collisions. When an UAV is moving according to SRCM, it has a larger scanning area because the mobility radius. The scanning time of a target is large enough because of the smoothness of the flight path. Potential dangers are avoided because UAVs and their neighbours exchange information about their position when they move their flight circles from one circular path to another.



(a) The semi-random circular movement model

(b) Column Mobility Model

(c) Nomadic Community Mobility Model

Fig.2. Group mobility model

The Column Mobility Model [13] is useful for scanning or searching purposes. It represents a set of mobile nodes that move randomly around a given line via an entity mobility model. For the implementation, an initial reference grid is defined where mobiles nodes are placed in relation to their reference point. Then for each node, a new reference point is calculated via a random distance and a random angle. Fig. 2(b) illustrates the movement in the Column Mobility Model. The UAVs (gray circles) are roaming around their respective reference points (black circles). The UAVs are always flowing the grid.

The Nomadic Community Mobility Model [13] represents groups of mobile nodes that collectively move from one point to another. So when the reference point changes its location the member of the group follow it to reach the new defined area. Within each group, the members maintain their own personal spaces, where they move in random ways around the new reference point. The parameters for the entity mobility model define how far mobile node may roam from the reference point. Here the nodes may be allowed to travel for 60 seconds before changing direction and speed un like the case in Column Mobility Model where nodes may only travel for two seconds before changing direction and speed.

The fig. 2(c) illustrates the movement in the Nomadic Community Mobility Model. In that illustration the black circle represents the reference point, and it is moving from a position to another. The grey circles represent the UAVs, and they are following the reference point.

The Pursue Mobility Model [13] is used to represent mobile nodes tracking a particular target. For example, this model could represent pursuing and filming an escaped criminal. This mobility model permits to update the position of each mobile node via an entity mobility model, via previous node information (position, acceleration) and via target information (acceleration). Here the amount of randomness for each mobile node is limited in order to maintain effective tracking of the target.

The Reference Point Group Mobility (RPGM) model [13] represents the random motion of a group of mobile nodes as well as the random motion of the group members. Group movements are calculated based the logical centre of the group. Group members' movements depend of the group movement and are randomly chosen based on their own pre-defined reference points. The RPGM model was designed for disaster management scenarios such as avalanche rescue. Each group can be responsible for a specific area or a specific task. The Nomadic Community Mobility Model and the Pursue Mobility Model are special cases of the RPGM model.

V. COMMUNICATION PROTOCOLS

Designing aeronautical wireless data links for UAS is more challenging than other wireless links. The key challenges are long distance, high speed and radio frequency spectrum.

In order to be effective in their assigned tasks, UAVs must be provided with a capability to communicate efficiently among each other as well as with the existing on-ground infrastructure networks and the internet. So for UAV to UAV communication and for UAV to infrastructure communication various protocols are defined.

In this section existing and specific wireless technologies are presented.

A. Existing wireless technologies

Many existing wireless technologies were applied for the drone communications. All of them permit a low energy consumption and almost use the ISM band.

1) Wifi (IEEE 802.11)

IEEE 802.11n and IEEE 802.11ac permit to acheive the best performances. Interessant features (in version n) such as Orthogonal Frequency-Division Multiplexing (OFDM), Multiple Input and Multiple Output (MIMO) techniques, beamforming transmission, space time block coding and cyclic delay diversity, permit the improvement of the network throughput (the data rate is up to 150 Mbps) and the improvement of the coverage rang (up to 250 m for outdoor). Other interessant features (in version ac) are Multi-User MIMO (MU-MIMO), efficient modulation and increased bandwidth which permit a further improvement of the network throughput (the data rate is up to 6.77 Gbps). But this standard has a limited communication rang (only 100 meters) and it supports a limited mobility.

IEEE802.11n can be used for the distribution of sensor data from a UAV to ground control stations. This technologie is able to satisfy the sensor data distribution requirements (in term of frame rate, image quality and acceptable delay) of different UAV applications such as 3D reconstruction, forestry and precision agriculture [17].

WiFi radio can be used between UAVs and the Incident Management System (IMS) to prevent disasters from occuring due to fires and gas leaks in collapsing building [18].

2) XBee

The first XBee radios were introduced under the MaxStream brand in 2005 and were based on the 802.15.4-2003 standard designed for point-to-point and star communications. It achieves a data rate of 250 kbps. XBee nodes can extend their coverage (up to 1.6 km) through the use of specific routing strategies (multi-hop). XBee is not adequate for the exchange of a large amount of data, such as images and videos, but it is appropriate for transferring data related to sensors monitoring and control.

A Xbee-PRO 900HP module can be adopted as wireless communication module, it can send real time data to the ground station for further processing and analysis and can receive command from the ground station. The transmitted data could be signals such as air pressure, acceleration and temperature detected by the UAVs [19].

To operate safely in difficult environmental conditions (for example after an earthquake), an UAV (quadrotor type) could be used as well as one data transmission link and two different video links. XBee modules are used for data transmission link. Which is a bidirectional link used to send telemetry data from the aerial vehicle down to the ground control station, and to send the control data in the opposite way [20].

3) *LTE*

Long Term Evolution (LTE) is a standard of wireless communication that allows operators to achieve high throughput in higher spectrum bandwidth. The objectives for LTE are to permit full vehicular speed mobility and coexistence with HSPA and earlier networks. This standard supports high mobility, long distance, low latency, all the requirement for drone's communication. But it can only be used in licensed bands.

In [21] a swarm of Unmanned Aerial Vehicles (UAVs) equipped with cellular technology can be used to temporarily offload traffic into neighboring cells in LTE/4G networks.

4) *ZigBee*

ZigBee is based on an IEEE 802.15.4 standard. It provides self-organized, multi-hop, and reliable mesh networking with low energy consumption. ZigBee has a variable range of coverage; it goes from 10 to 150 m with a maximum data rate of 250 kbps. This technology can be used for the communication between Wireless Sensor Network (WSN) nodes and UAVs. Data sensed by the sensors can be sent rabidly and in real time. This wireless communication can be used in the context of monitoring and computing greenhouse gases[22], or in the context of fires and gas leaks detection in building [18].

5) *WiMAX (IEEE 802.16)*

This standard supports speeds up to 120km/h and a range up to 30 km. WiMAX allows higher data rates over longer distances, efficient use of bandwidth and offers minimal interference.

WiMAX standard is more preferable compared to other existing technologies for drones communication in alpine environment [23]. In fact it was chosen as a solution because of its flexibility, safety, ability to manage the quality of service, high throughput, easy installation, ability to manage the mobility, low cost, capacity to cover large area and its utilization in both licensed and unlicensed band.

During emergency situations such as natural events or terroristic attacks, a network solution based on UAVs and WiMAX technology can be realized. UAVs can be are equipped with WiMAX technology to communicate with each other and with the terrestrial terminals. In fact UAVs are positioned over the emergency area and create an adaptive wireless mesh network backbone to allow the emergency communications. [24].

B. *Specific wireless technologies (safety and air navigation)*

The European organization for the Safety of Air Navigation (EUROCONTROL) has funded two groups to developed two separate proposals for UAS aeronautical communication links. So L-Band Digital Aeronautical Communication Systems of Type 1 (L-DACS1) and L-Band Digital Aeronautical Communication Systems of Type 2 (L-DACS2) were developed and now they are potential candidates for adoption [25].

L-DACS1and L-DACS2 use the L-Band because HF and VHF bands are getting very congested. Lower frequency bands are preferred because when going up in frequency, the loss will go up.

L-DACS1 is based on B-AMC, P34 and WiMAX. It uses multi-carrier modulation, physical layer allocation maps and allocation units similar to those in WiMAX. L-DACS2 is based on GSM. It uses the physical layer and GMSK (Gaussian Minimum Shift Keying) modulation of GSM.

The characteristics of L-DACS1 and L-DACS2 are presented in table I.

TABLE I. CHARACTERISTICS COMPARISON BETWEEN L-DACS1 AND L-DACS2

	L-DACS1	**L-DACS2**
Single-Carrier vs. Multi-Carrier Modulations	The multi-carrier design permits a flexible spectrum placement, interference avoidance and co-existence.	With single-carrier radios it is difficult to adapt to different frequency possibilities.
Spectral Efficiency	0.6 to 2.76 bps/Hz in the forward direction and 0.44 to 2.08 bps/Hz in the reverse direction.	1.3 bps/Hz in forward and reverse direction combined
Duplexing (TDD vs. FDD)	FDD is suitable for symmetric voice traffic but less suitable for data.	TDD allows asymmetric data traffic.
Physical Layer Framing	The time is divided into 240 ms intervals called superframes. In the forward and reverse direction, each superframe begins with a 6.72 ms region followed by 4 multiframes.	The time is divided into 1 second frames. Each frame is divided in two uplink sections, two downlink sections, and one login section.
Net Interference	–22 dBm	–10.8 dBm (affected because its frequency spectrum is very close to that used by GSM)

C. *Specific wireless technologies (US military communication)*

To meet the requirements of military communication, new technologies which correspond to the physical layer and the link layer in the OSI model were proposed [10]. The current generation of data link aims to facilitate and secure the operations. Then a next-generation data link systems was proposed to facilitate communications in decentralized UAV networks.

The current data links are used for secure and efficient communication between air, surface, subsurface and ground. There are the Common Data Link (CDL), the

Tactical Common Data Link (TCLD), the Link-11, the Link-14, the Link-16 and the Link-22. Joint Tactical Radio System (JTRS) is a tactical data link used for military operations where critical information are exchanged. It is included in the category of the next-generation data link.

Table II compares the different data rates and frequency bands used in US military wireless technologies.

TABLE II. CHARACTERISTICS OF US MILITARY DATA LINKS

	Data transmission rate	**Frequency band**
CLD	uplink: 200 Kbps. downlink: 10.71 Mbps, 137 Mbps, or 274 Mbps.	Up-link: X-band (9.750 - 9.950 GHz), Ku-band (15.15 - 15.35 GHz). Down-link: X-band (10.150 - 10.425 GHz), Ku-band (14.40 - 14.83 GHz)
TCLD	uplink: 200 Kbps. downlink: 10.71 Mbps.	Uplink: Ku narrow-band. Downlink: wide-band
Link-11	Link-11A: (1.364 2.25 kbps)	High frequency (HF) band (3-30 MHz) or the ultra high frequency (UHF) band (225-400 MHz).
Link-14		HF, VHF, or UHF band
Link-16	up to 115.2 kbps.	L-band (969- 1206 MHz)
Link-22	127 kbps	HF or UHF band
JTRS	1.2 Mbps	from 2 MHz to 2 GHz

VI. RESEARCH CHALLENGES

The trend now is the use a groups of autonomous UAVs that are working in a cooperative manner to achieve risky missions in dangerous environment. Also for developing collaborative UAVs applications, a cloud can be used to simplify the efforts and reduce the time and the cost needed [26]. UAVs can use the cloud services and resources while the cloud applications can use UAVs as providers for services. This proposed cloud offers different opportunities in UAVs applications development and deployment. Moreover human/automation collaboration can be benefic and can improve the UAS performance [27]. Automated planners are faster than humans for path planning and resource allocation, but they are unable to respond to emergent events that's why humans must guide them. So the operator is responsible of making the strategic decision such as where to focus the search and which tasks should be included and approved.

New technologies are considered to innovate in the design and use of the UAVs [1]. Advances in integrated circuit are making possible to build more sophisticated chips (in term of size, power and quality). Advances in airframe design and flight control methods are making possible to build smaller and more capable unmanned aircraft. Advances in wireless communication and networking are making possible to deliver real time information from the unmanned aircraft to the operator. Challenges are also choosing for every application and every mission a specific topology, a specific mobility model and a specific communication protocol, since every mission has its requirements.

Furthermore when considering surveillance and security systems, it is important to transmit image information with high quality and to ensure a good treatment of the received information. Many approaches are being considered to ensure a good quality of service.

The implementation of the OSI model for UAV ad hoc network may not fit well due to some constraints imposed by the UAV such as the mobility. Also this architecture is not flexible enough to achieve certain quality of services (QoS). So the cross layering technique was introduced [28], which consist in allowing the communication between layers even when they are not adjacent. This permits to achieve more efficient communications, to improve reliability of links while minimizing the symbol error probability.

VII. CONCLUSION AND FUTURE WORK

In this paper, we presented the Unmanned Aerial System (UAS) and its main components which are the UAVs. In fact they are responsible of delivering the information and together they are forming a FANET. Then FANET features were presented such as high mobility and frequent topology changes. After that, UAVs applications were presented. Disaster management, disease management, agriculture management are examples of UAV applications. According to the application, many topologies can be applied and many mobility models can be chosen. The topology can be centralized (involving UAVs working individually) or it can be decentralized (involving UAVs working in a group). Those topologies were presented in section III. The mobility models were analyzed, in fact they can be applied to individuals moving in a probabilistic way or in a random way, this is called entity mobility models. The other type of the mobility models is the group mobility model which is applied to a group of UAVs working in a cooperative manner.

We have presented many communication protocols. WiMAX and LTE are examples of existent communication protocols. L-DACS1 and L-DACS2 are examples of communication protocols for safety and air navigation.

The communication protocols ensure the communications between the FANET and the external network such as sending back the sensor data and receiving the control commands. They ensure also the communication in the FANET between UAVs such as cooperative trajectory planning and dynamic task assignments. This communication can be direct or multi-hop over other UAVs and can benefit from mesh routing protocols.

While designing new data links, we must consider the distance, the speed and the frequency spectrum. Ensuring high coverage, high speed and high spectral efficiency can be very challenging. Also when using those UAVs, some questions and problems are raised. Respecting privacy and ethics, ensuring safety and good data quality are fundamental requirement for successful UAVs operations [29]. Ensuring safety involves the capacity of UAVs to sense and avoid other aircraft. Providing good data quality is essential to the success of the mission. Respecting privacy and ethics is the respect of human beings in general.

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