ON THE CONCEPTS AND CHALLENGES OF FLYING AD HOC NETWORKS (FANETS)

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ABSTRACT
As a result of technological advances on robotic systems, electronic sensors, and communication techniques, the production of unmanned aerial vehicle (UAV) systems has become possible. Their easy installation and flexibility led these UAV systems to be used widely in both the military and civilian applications. Note that the capability of one UAV is however limited. Nowadays, a multi-UAV system is of special interest due to the ability of its associate UAV members either to coordinate simultaneous coverage of large areas or to cooperate to achieve common goals / targets. This kind of cooperation / coordination requires reliable communication network with a proper network model to ensure the exchange of both control and data packets among UAVs. Such network models should provide all-time connectivity to avoid the dangerous failures or unintended consequences. Thus, the multi-UAV system relies on communication to operate.

In this paper, current literature about multi-UAV system regarding its concepts and challenges is presented. Also, both the merits and drawbacks of the available networking architectures and models in a multi-UAV system are presented. Flying Ad Hoc Network (FANET) is moreover considered as a sophisticated type of wireless ad hoc network among UAVs, which solved the communication problems into other network models. Along with the FANET unique features, challenges and open issues are also discussed.

1. INTRODUCTION
The progresses on miniaturization technologies in addition to the development in both communications and embedded systems have paved the way for producing various types of low cost UAVs [1], [2]. Unmanned Aerial Vehicles (UAVs) is an aircraft that flies either fully autonomous (without any human intervention) or remotely (controlled by a ground base station) to operate in a wide range of the missions and emergencies. The operational experiences with UAVs have shown that their technologies open new ways not only for military applications but also for civilian applications. This includes, but is not limited to, radio source localization [3], surveillance [4], [5], transportation of suspended loads [6], [7], relaying for ad hoc networks [8], search and destroy missions [9], reconnaissance and surveillance, maintaining of the weapon systems network, combat support [10].

In the last decade, single-UAV systems have been utilized in different applications. While the number of UAV increases, the design of efficient network architecture becomes a vital issue in single-UAV systems to solve. By means of the technological advancement in avionics and micro-electromechanical systems, the utilization of the multi-UAV system to perform missions has been emerged [11]. It's worth noting that using multiple UAVs instead of a single one yields wide range of advantages, which we will try to summarize them as follows [12–18]:
- Multiple simultaneous interventions.
- Greater efficiency.
- High Reliability.
- Complementarities of team members.
- Low Cost.
- Increasing accuracy.
- High Scalability.
- Low Detectability.

Accordingly, groups of UAVs are of special interest due to their ability to coordinate simultaneous coverage of large areas or cooperate to achieve common goals [19]. In order to ensure a global coherence within the whole system, one main requirement is to have a successful coordination and cooperation by sharing information as mentioned in [20]. Typically, two types of information are shared by a multi-UAV system, one of which involves command and control messages and the other is the mission data remotely sensed and gathered by the airborne
sensors on UAVs and then transmitted to fusion centers [21]. It is worth emphasizing that fusion center process, exploits, and disseminates the mission data. Thus guaranteeing that UAVs are in communication most of the time during the mission and sharing the information is critical for multi-UAV system in order to function properly. Accordingly, the network and communication systems are the fundamental components of the multi-UAV system. As a result of the fact that the multi-UAV system is rapidly developing and the scope of its usage grows greatly, the networked communication will become the most crucial issue that needs a vast interest by researchers.

This paper is organized as follows: In Section II, we presented the coupling and networking in Multi-UAV system. The concept and challenges of Flying Ad Hoc Network (FANET) and its open issues are presented in the following section. Then we conclude in the last section.

2. COUPLING AND NETWORKING IN A MULTI-UAV SYSTEM

UAVs have become promising mobile platforms due to its capabilities to navigate simultaneously or autonomously in uncertain environments. On the side as depicted in Figure 1, a network with flying nodes requires synergistic interactivity between the four design-principle dimensions: control system, network & communication, information sharing and situational awareness [22]. Thus, bringing group of UAVs into a team requires significant coordination efforts to perform a given objective. For that reason, each UAV readily guarantees to be placed appropriately with respect not only to its neighbors but also to its tasks within mission plan, which imposes the existence of a precise decision maker (controller) for both path planning and task allocation in addition to the availability of efficient network system.

In what follows, two important concepts in the multi-UAV system are presented; one of which is coupling. The other one is networking. Coupling takes into account how relationship exists among UAVs, while networking readily characterizes the communication status among UAVs as well as the ways in which the data are transmitted within whole system.

Figure 1. DESIGN PRINCIPLES OF NETWORK WITH FLYING NODES.

In what follows, two important concepts in the multi-UAV system are presented; one of which is coupling. The other one is networking. Coupling takes into account how relationship exists among UAVs, while networking readily characterizes the communication status among UAVs as well as the ways in which the data are transmitted within whole system.

2. COUPLING TYPES IN MULTI-UAV SYSTEM:
(a) physical coupling, (b) formations, (c) swarms, and (d) Intentional cooperation.

2.1 Coupling in a multi-UAV system

As shown in Figure 2, there are two types of coupling in multi-UAV system. The first type is a physical coupling while the other is not physical, and therefore we can call it a logical coupling. In what follows, the details of all coupling types in addition to their possible applications are presented.

2.1.1 Physical Coupling

Within this kind of coupling, there are physical links that connect the UAVs to each other. The motion of an UAV is constrained by forces that are originated as a result of motion of the other UAVs in system, which remains an open problem for researchers. One of the applications of this type of coupling is to cooperatively lift & transport suspended loads using multiple UAVs. In more details, it is a nature extension of collaborative behavior of several persons to move an object that is too heavy to be carried by a single person. The UAVs take into account not only the consideration of physical interactions between them, but also the involved forces induced by the suspended payload. Flying with a suspended load is a challenging and, sometimes hazard task. Thus, not only designing of a control system that considers the effects of the suspended load on the flight characteristics but also providing the stability of the vehicle-load system remain an open problem for researchers and practitioners [6], [7].

2.1.2 Logical Coupling

a. Formations: UAVs perform a cooperative task by flying in a formation as a group, where a formation flight means that the members of the UAV group must keep a fixed distance among themselves within other group and thus whole group moves as a rigid entity in a desired shape [23]. At the present time, many
formation control strategies are proposed; however, there are mainly three approaches are used, namely, leader-follower [24], virtual leader [25], and behavioral approach [26]. Each formation has many applications such as surveillance, radar deception, and surface-to-air missile jamming. Indeed, how to define the practical architectures for formation in addition to the signal flows that associated with communications, sensing and control are crucial issues that need a vast interest by researchers.

b. Swarm: In these days, the current technology enables us to mimic the behaviors of varied types of insects (or birds). Indeed, we are able to create accurate artificial simulations for their interactions not only among each other, but also with their surrounding environment [27]. One of these emerging behaviors that can be used in the multi-UAV system is a swarm. UAVs swarm means forming of teams of homogeneous UAV interacting with each other to generate complex collective global behaviors; nevertheless, it does not necessarily mean that the resulting motion leads to a formation [28]. Swarm cooperation involves many repetitions of the same activity over a large area. Moreover, a member within a swarm commonly moves in random depending on the movement of others to generate the corresponding action. While the multiple UAVs are organized into a swarm, the new challenges such as providing a robust local communication and proposing an effective control mechanisms that collectively achieve goals without a collision need to be addressed by researchers in order to obtain effective swarm management. The swarm of multiple UAVs is practical for many applications, for instance, the assessment of forest environments [29], and coordinated search [30].

Figure 3. DIRECT COMMUNICATION ARCHITECTURE.

c. Intentional cooperation: In this type of coupling, the global mission of a multi-UAV system is performed according to particular planning strategies by which a set of tasks (sub-goals) are explicitly allocated to each UAV. Consequently, UAVs of the team move along specific trajectories in order to execute these individual tasks. However, the UAV trajectories are not geometrically related as mentioned in the case of formation coupling. Therefore, the overall goal of the multi-UAV system will be achieved in an intentional cooperation scheme [31]. It is however worth noting that in the intentional coupling, different issues and considerations such as multi-UAV task allocation, communication guarantee, conflict-resolution, plan decomposition and UAVs heterogeneity has to be taken into account when implementing the global mission [28]. Recently, intentional cooperation scheme is used in many civil applications, for instance, fire confirmation, extinguishing, and monitoring.

2.2 Networking in a multi-UAV system

Describing the characteristics of the data transmission over the entire multi-UAV system plays an important role in selecting a networking architecture for the best performance. Therefore, there exist different networking architectures proposed and emerged [32]. The simplest one is to have direct communication links between UAVs and single ground station in a star topology, where a ground station is simply responsible for creating the communication between these UAVs as well as coordination their motions. It is however worth noting that communication ranges of UAVs, which certainly depend on movement, terrain structure and dynamic environmental conditions, certainly restrict the operation area. Moreover, the usage of a ground control station (GCS) might result in traffic congestion that accordingly influences system functionality. Figure 3 depicts a multi-UAV system simply employing direct communication architecture.

There exist the other three possible network architectures proposed for the multi-UAV system as depicted in Figure 4. These types are satellite, cellular and ad hoc [33] each of which solves or alleviates the problems in direct link approach. The details of these three types are discussed as follows:

a. Satellite: Using satellite architecture provides a better coverage more than using direct link architecture. Specifically, UAVs connect to a satellite instead of a single ground station. Due to the fact that there exist obstacles and structures between satellite and UAVs less than the other communication architecture type of architecture, the deteriorating effects on communication links will be decreased. The operational area is also extended as a result of the a wide communication range of a satellite. On the other hand, this type of architecture suffers from other drawbacks. UAVs-to-satellite connections need to mount heavy and expensive airborne satellite communication hardware on each UAV [32]. Thus, the increase in the number of UAVs leads to increase the total cost of the multi-UAV system. Moreover, under harsh weather conditions, the wireless links between the UAVs and satellite will be subject to outage.

b. Cellular: The network architecture that is similar to the ubiquitous mobile telephone infrastructure. It involves more than one ground station scattered on the ground. Thus, UAVs can do a handover between different base stations during the flight. Cellular architecture provides a good level of network connectivity and reliable data delivery. However, the multiple ground station architecture is an expensive network because of the high cost of each tower and its equipment [28].

c. FANET: In this networking architecture the wireless ad hoc network among UAVs is established where all UAVs could work
as a relay node. These relay nodes work together in order to forward the data until it reaches the destination [34]. FANET involves two segments according to the used communication type. The first one is called “ground or satellite segment” in which some of UAVs can directly communicate with ground station or via satellite in UAV-to-infrastructure communication type while the other called “aero segment” in which the UAVs do not have any direct links with the ground station and can connect to each other. This type of communication is called UAV-to-UAV communication.

3. THE CONCEPT, CHALLENGES AND OPEN ISSUES IN FANET

It is important to emphasize that changing in the orientation from using one UAV to using several small UAVs needs to develop new networking technologies among UAVs. FANET is within that context considered as a popular technology for a communication networking among multi UAVs as a result of not only extending the operational scope and ranging but also enabling quick and reliable response time. However, setting up an ad hoc network among UAVs imposes challenging issues and needs some additional requirements different from those a traditional network needs. In this section, the concepts of FANET and its open issues and challenges are presented.

3.1 Concept and Unique Features

Recently, one of the most prestigious technologies in the communication and networking is FANET. It is a kind of self-organized wireless network carried by a group of UAVs each of which is a small flying robot [35]. It is worth mentioning that FANET is a very attractive technology for many applications, especially in the case of the calamitous events where the infrastructure operation mode is not available. The construction of self-managed wireless ad hoc network by using a group of small and rapidly deployable UAVs will be a feasible solution on these events. In addition, FANET has many usage scenarios which lead not only to increase both reliability and collaborative actions to perform complex tasks but also reduce payload and cost [32]. Thus, FANET significantly outperforms on the other communication structures of multi-UAV system.

As shown in Figure 5, FANET can be considered as a special form of mobile ad hoc network (MANET). Moreover, it can also be considered as a subgroup of vehicular ad hoc network (VANET). In spite of fact that FANET has common features with MANET and VANET, it apparently possesses unique features distinguished from their features. For example, when FANET is considered three dimensions span in location of UAVs, the MANET considered two dimensions in location of nodes (e.g. Mobile users in area), while VANET generally considered single dimension span in location of vehicles (e.g. The vehicles on the road). These main differences between FANET and the current ad hoc networks are listed as follows:

- **High Mobility** [36–38].
- **Rapid Topology Changes** [39–41].
- **Long Distance** [42–44].
- **Low Node density** [34, 45, 46].
- **More Flexibility** [45, 47].
- **Minimal Latency** [34,40].

Consequently, these vital issues impose another constraints and challenges that must be taken into account by any researcher work in this area. For instance, a high mobility and rapid topology changes have a main effect on the mobility model design. In addition, the long distance and low density require a good study on the RF propagation and antenna design in FANET. Moreover, the routing strategies and its information updating mechanisms need to be more flexibility to keep pace the latency constraint.
3.2 Open Issues and challenges

The distinct characteristics of FANET-based multi UAV systems promise a vast usage for both military and civilian spaces not only because of its versatility and flexibility but also the capacity of its UAVs to be deployed as a communication relay. However, it also brought the new challenging issues and additional burdens on the physical, Medium Access Control (MAC) and network layer designs. In this section, we review the researches, which have been performed to address with these challenges in addition to some of open issues for future works.

a. **UAV airframe constraints**: The space of UAV airframe is considered one of the challenging issues in FANET design. In FANET, UAVs are usually a small size and their airframes actually have a limited space [48]. The UAV payload and communication hardware should be contained within this airframe. Consequently, the space limitation of airframe plays an important role in determining the size, weight, and power (SWAP) of the onboard hardware and thus their performance. It is important to note that when the FANET network is designed taking into consideration trade-off between payload and communication hardware size to be fitted into the UAV airframe commensurate with the desired missions. In addition, attempt designing an UAV from lightweight materials will help to mitigate this problem [49].

b. **Mobility Models**: The mobility models are one of the simulation environment features, which are designed to describe the movement patterns of mobile nodes, and how their location, velocity and acceleration change over time. They play a significant role in determining the ad hoc network performance [50]. Mobility model has to be matched to the expected real environment by capturing a realistic mobility pattern in which one wants to operate the network [51]. It is therefore necessary to choose a proper underlying mobility model appropriate for each ad hoc network design characteristics like FANET.

Some FANET applications prefer using global path plans. In this approach the UAVs move on a predetermined path and thus mobility model will be regular. However, the flight plan in autonomous multi-UAV system is not predetermined because of environmental changes or the mission updates even if there are a predefined flight plans are used. A novel mobility model based on semi-random circular movement (SRCM) is presented in [52]. In this model, UAVs rotate clockwise (or anticlockwise) along a predefined circle with a velocity and a central angle chosen uniformly at random in the certain interval. The SRCM model is suitable for simulating UAVs in quite a number of movement scenarios requiring circular movement such as gathering information from specific locations.

Bouachir et al. presented in [53] a paparazzi mobility model (PPRZM) that is a realistic mobility model designed for UAV ad hoc networks based on the five possible movements of Paparazzi UAV (Stay-At, Way-Point, Eight, Scan and Oval). These movements have different probabilities to occur. In PPRZM, each UAV chooses a movement type and fixes its characteristics (Location and Speed). Thus, UAVs are assigned a specific position and follows a well-defined path according to the movement chosen. The mobility model in multi-UAV swarms represents another approach. In [54], the authors proposed a scenario consist of two levels of UAV swarms, one is fixed-wing UAVs swarm with high altitude (the backbone network) and the other is rotary-wing UAVs swarm with low altitude. In addition, the mobility of a low-level swarm system is divided into two types of mobility models which are the pheromone mobility model and the other is a mobility model with k-hop clustering algorithm (KHOPCA) that aims at keeping a stable and connected network. At the end, the final results show the validity of the KHOPCA-based model in improving the network stability in multi-level UAV swarms.

Accordingly, the proposed mobility models have great effects on the accuracy of FANET simulation outcomes. As a result, these models should be representative of reality with respect to
the intended real application. Thus, the designing of FANET mobility models will become the vital issue that needs a big interest by researchers.

**c. Physical Layer:** Since FANET is considered as a special case of MANET, it is highly dependent on its physical layer of communication. Therefore, the quite high mobility in FANET will add extra challenges and issues that must be solved [34]. In fact, obtaining a robust and consistent data communication architecture, the physical layer conditions have to be well defined and understood. In this section the radio propagation model and antenna structure are investigated as the key factors on the physical layer design.

- **Radio propagation model**
  Radio waves radiate from the transmitter antenna and then propagate through environments where they are reflected, scattered, and diffracted by walls, terrain, buildings, and other objects. This dictates that the characteristics of the radio waves change as they travel to the receiver antenna. In fact, these characteristics depend upon the distance between the two antennas, the path(s) taken by the signal, and the environment (buildings and other objects) around the path. The radio wave propagation and its characteristics can be expressed as mathematical functions that are called radio propagation modeling [55]. In comparison with the other types of wireless networks, FANET has several unique features in terms of radio propagation, which are summarized as
  
  i. Interferences and jamming,
  ii. Shadowing caused by UAV platform and its equipment,
  iii. Environmental effects,
  iv. Effects of ground reflection,
  v. High mobility that causes variations in communication distance,
  vi. The effect of UAV attitude and speed motion (Doppler effect) on the link quality.

Accordingly, the quality of wireless communication links varies over time in FANET [56]. There are indeed many researchers investigating a wireless technology for communication in FANET. For that reason, modeling (i.e., statistically characterizing) the fading conditions in wireless communication requires more attention for a feasible FANET network. Zhou et al. investigated in [57] the channel-modeling problem for UAV-to-UAV communication, and proposed a two-state Markov model to incorporate the effects of Rician fading, depending on the changes of the distance between UAVs. The simulation results showed that the errors statistics are non-stationary of the wireless channels between UAVs. For feasible cooperative UAV network, the outage probability over Nakagami-m fading channel has been analyzed in [58]. The received signal strength in a multi-path fading environment is estimated in this model, and it is simply defined as a function of two parameters: (i) the fading intensity and (ii) the average received radio signal strength. It is proposed that the fading conditions in the radio propagation in FANET communication is modeled by Nakagami-m fading distribution. Note that the most generalized fading distribution, which can be effectively used as a model in the performance analysis of FANET network, is known as Extended Generalized-K (EGK) whose distribution is defined as [59], [60]

\[
p(\gamma) = \frac{\xi}{\Gamma(m_s)\Gamma(m)} \left(\frac{\beta_s\beta}{\Omega}\right)^{m\xi} \gamma^{m\xi-1} \times \Gamma\left(m_s - m \frac{\xi}{\xi_s}, 0, \left(\frac{\beta_s\beta}{\Omega}\right)^{m\xi} \gamma^{\frac{\xi}{\xi_s}}\right),
\]

where \(0 < \gamma < \infty, \) and where the parameters \(m (0.5 < m < \infty)\) and \(\xi (0.5 < \xi < \infty)\) represent the fading figure (diversity order) and fading shaping factor of the communication links among UAVs, respectively, while \(m_s (0.5 < m_s < \infty)\) and \(\xi_s (0.5 < \xi_s < \infty)\) represent the shadowing severity and the shadowing shaping factor of those links, respectively. The parameter \(\Omega\) denotes the average power. It is important to stress that the shadowing factor parameter statistically models the obstacles & structures and inhomogeneity composition of the air among UAVs. Moreover, \(\beta\) and \(\beta_s\) are defined as \(\beta = \Gamma(m + 1/\xi)/\Gamma(m)\) and \(\beta_s = \Gamma(m_s + 1/\xi_s)/\Gamma(m_s),\) respectively, where \(\Gamma()\) is the Gamma function [61, Eq. (6.5.3)]. In addition, \(\Gamma(c; \alpha, \beta)\) is the extended incomplete Gamma function defined as \(\Gamma(a, x, b, \beta) = \int_x^\infty r^{a-1} \exp(-r - br - \beta)dr\) with parameters \(a, b, \beta \in \mathbb{C}\) and \(x \in \mathbb{R}^+\) [62, Eq. (6.2)]. In order to discover / disclose possible extreme situations, the analysis of the applications within FANETs should incorporate this fading model, especially, especially in low altitude crowded area applications.

- **Antenna structure**
  One of the most crucial factors for an efficient FANET communication architecture is the antenna structure. Actually, The distance between UAVs in FANET is longer than the typical distance in other wireless ad hoc networks. This long distance has the direct effect on the FANET antenna structure. One of the solutions to overcome this problem is the use of high transmission power. However, this higher transmission power may result in more interference in FANET and also the high link loss and variation could still arise. In order to overcome this phenomenon, Kung et al. proposed in [63] exploiting the channel’s spatial / temporal diversity by using a multiple transmitter and receiver nodes that cooperate to improve overall packet reception. Another factor that affects the FANET performance is antenna type. Indeed, there are two types of antennas are utilized in FANET applications: omnidirectional and directional. In omnidirectional antenna, the electromagnetic waves are sent to all directions while they are sent to a desired direction in directional antenna.

Accordingly, we can understand that the characteristics of the physical layer affect the design the other layers and thus the overall FANET performance. For this, the researchers should inves-
tigate the accuracy on their studies for the physical layer. Moreover, the performance analysis of the physical layer must be done in 3D environment instead of 2D as is the case in most of the current studies.

d. MAC Layer: A FANET is a novel and upcoming mobile wireless ad hoc network. In this sense, the first examples of FANET use IEEE 802.11 MAC layer. However, the distinctive features of FANET such as its high mobility, variable link quality, and varying distances between UAVs impose new challenges on the FANET MAC design that need to be thoroughly studied by researchers. Two promising technological advancements can be used to handle these problems: directional antenna and full-duplex radio circuits.

In [64], Temel and Bekmezci proposed a Location Oriented Directional MAC (LODMAC) for FANETS that incorporates the location estimation of the neighboring nodes and directional antennas within the MAC layer. This study showed that LODMAC increases the spatial reuse and overall network capacity of FANETs in 3D space. In the same orientation, Alshbatat and Dong proposed Adaptive MAC protocol for UAVs (AMUAV) [65]. AMUAV is a directed antenna-based MAC protocol that uses omnidirectional antenna to send the control packets (RTS, CTS, and ACK) while using a directional antenna for sending data packets. Wireless nodes cannot transmit and receive data packets at the same time on the same channel for a long time, and also these nodes are incapable of receiving multiple packets simultaneously. However, with the current enhancements in communication technology, the full-duplex scheme of wireless communication became available. In this scheme, wireless nodes are able to exchange their data over the same frequency band and but without any discontinuities in time. Moreover, by using multiple packet reception (MPR), it makes each node capable of receiving multiple packets simultaneously [66].

It is accordingly obvious that one of the promising technologies for creating powerful MAC protocol is to use of the directed antenna. However, sharing the estimated location information among UAVs is considered as a crucial issue of this type of MAC protocols, which needs to be investigated and solved by the researchers.

e. Network Layer: The primary purpose of a wireless ad hoc network routing protocol is to implement a correct and efficient route establishment between a pair of wireless nodes so that messages could be delivered in a timely manner [67]. There are number of routing protocols currently available in wireless ad hoc networks which have been designed and classified depending on different criteria, the main seven criteria of which are listed as follows:

- **Routing information computation** [67, 69–71].
- **Structure (flat or hierarchical)** [72–76].
- **Number of routes (single or multiple route)** [67, 77–79].
- **Route information level (source routing or Hop-by-Hop)** [80–84].
- **Energy consumption** [85–88].
- **Casting packet** [89–92].
- **Topology or location information** [40, 75, 93–96].

One of the main effects on the routing protocol functions is the pace of network topology changes. The routing protocols must be able to update routing tables or cashes dynamically based on these changes on topology [97]. The dynamic nature of FANET results in frequent changes in the network topology and thus makes the routing process among UAVs in FANET a daunting task that needs to be addressed by researchers. In fact, some specific ad-hoc networking protocols have been implemented and some of the previous ones have been modified in order to be feasible in FANET. Rosati et al. presented the Predictive-OLSR protocol [98]. The Predictive-OLSR is a proactive link-state routing protocol with capability to enable efficient routing in very dynamic conditions. It is an extension of the Optimized Link-State Routing (OLSR) protocol [68, 99, 100]. As in OLSR protocol, this protocol uses receiving ratios (r_f and r_s), but it redefines the ETX metric to be a Speed-Weighted ETX metric by using the relative speed between two nodes and also using fresh GPS information to improve the routing. Thus, the authors redefined the ETX as

$$\text{ETX}_{i,j} = \frac{v_i^{i,j} \beta}{r_f \, r_s}$$

\[ (2) \]

and

$$\begin{align*}
\nu_{i,j} &= \gamma \, w_{i,j} + (1 - \gamma) \nu_{i,j-1} \\
\nu_0 &= 0
\end{align*}$$

\[ (3) \]

$$\begin{align*}
r_f &= \alpha \, h_i + (1 - \alpha) r_{f-1} \\
r_0 &= 0
\end{align*}$$

\[ (4) \]

where $\alpha$ denotes a link-quality aging ($0 \leq \alpha \leq 1$) and where the coefficient $h_i$ is defined as

$$h_i = \begin{cases} 1 & \text{if } l\text{th Hello packet received} \\ 0 & \text{otherwise} \end{cases}$$

And $\gamma$ and $\beta$ denote a predictive-OLSR (P-OLSR) parameter ($0 \leq \gamma \leq 1$) and a non-negative parameter, respectively. Moreover, $v_i^{i,j}$ and $w_i^{i,j}$ denote the relative speed and the instantaneous relative velocity, respectively, between UAVs i and j. As stated in [36], the P-OLSR is currently used as a FANET-specific routing protocol. Another extension to the (OLSR) protocol is a Directional Optimization Link State Routing protocol (DOLSR) [101]. DOLSR capable of decreasing the End-to-End delay by reducing the number of the multipoint relays in the network, and thus the number of overhead packets will be reduced.

The other approach in FANET routing protocol is the use of Reactive Routing Protocols (RRPs) such as Ad hoc On-demand Distance Vector (AODV) [69], AODV is capable of preserving the bandwidth consumed in Proactive Routing Protocol (PRP) as a result of periodically updating for routing table. On the other hand, AODV suffers from high latency appearing during the route finding process. In fact, finding repetitive path and maintaining the routing table together do not seem to be an optimal solution in high mobility environments. Thus, routing strategies based on the location information are used [93], [94]. Hyland and et al. compared in [102] the performance of three different routing strategies in the context of a swarm of UAVs. The results showed that the Greedy Perimeter Stateless Routing
The system functionality but also decreases the completion time. The paper, multi-UAV system not only increases the reliability of many advantages beyond a single UAV system. As explained in ground. Thus, multi-UAV system has been emerged that have especially in areas that are relatively inaccessible from the traditional full-size piloted aircrafts. Progressively, UAVs need to cooperate with each other in order to perform complex tasks through increasing security. Furthermore, Data Centric Routing (DCR) algorithm with publisher-subscriber model is so applicable in FANET [104] that it is preferred in point-to-multipoint data transmission when data is requested by number of nodes. Since the data request and collection within this routing protocol is simply accomplished according to data attributes, deriving novel mechanisms of data aggregation is the other resulting challenge that needs to be studied by researchers and practitioners.

As a result, inefficient routing of messages, commands and data among UAVs is to be a significant challenge in itself for FANET. Thus, the latency problem (i.e., delays) in addition to the other issues such as cost overhead to establish the multi-hop route, reliability in case of sparse deployment, dropped messages due to error, etc. are remained to be studied & analyzed by the researchers to find better solutions satisfying all FANET requirements.

Figure 6. LOAD CARRY AND DELIVER ROUTING.

CONCLUSION

UAVs have seen unprecedented levels of growth over the past 20 years with military applications dominating the field. However, UAVs have recently played a major role in a broader range of civilian applications and have gained popularity over traditional full-size piloted aircrafts. Progressively, UAVs need to cooperate with each other in order to perform complex tasks especially in areas that are relatively inaccessible from the ground. Thus, multi-UAV system has been emerged that have many advantages beyond a single UAV system. As explained in the paper, multi-UAV system not only increases the reliability of the system functionality but also decreases the completion time of system objectives. However, the multi-UAV system imposes the other challenges, which are mentioned in the paper (such as coordination and cooperation, controller design and collaborative mission requirements), need to be investigated by the researchers.

Information sharing, which means communication, is one of the most challenging design issues in the multi-UAV system. There are therefore lots of communication architectures, such as cellular and satellite, each of which has been proposed to create links among UAVs in the system. Despite all the advantages offered by these cellular- and satellite-based communication architectures, they are suffering a lot of the main issues / problems such as a limited communication range and the scalability as explained in the paper. In order to overcome these problems, FANET architecture, which is ad hoc network among nodes in multi-UAV system, has been proposed as the best solution possessing many merits and also challenges each of which must be taken into account by any researcher working in this area. Within that context, a comprehensive review of the recent literature on flying ad hoc network (FANET) in terms to its unique features, challenges and open issues are presented within the paper. Thus, FANET represents a new era of ad hoc networks, which will offer a wide range of future applications to the community. Consequently, lots of researchers and practitioners should study this type of ad hoc network to find solutions for the most challenging problems mentioned in the paper.

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