Flying Ad-Hoc Networks

Subjects: Engineering, Electrical & Electronic

Contributor: Fazal Noor , Muhammad Asghar Khan , Ali Al-Zahrani , Insaf Ullah , Kawther A. Al-Dhlan

Unmanned aerial vehicles (UAVs), also known as drones, once centric to military applications, are presently finding their way in many civilian and commercial applications. If national legislations permit UAVs to operate autonomously, one will see the skies become populated with many small UAVs, each one performing various tasks such as mail and package delivery, traffic monitoring, event filming, surveillance, search and rescue, and other applications. Thus, advancing to multiple small UAVs from a single large UAV has resulted in a new clan of networks known as flying ad-hoc networks (FANETs). Such networks provide reliability, ease of deployment, and relatively low operating costs by offering a robust communication network among the UAVs and base stations (BS). Although FANETs offer many benefits, there also exist a number of challenges that need to be addressed; the most significant of these being the communication one.

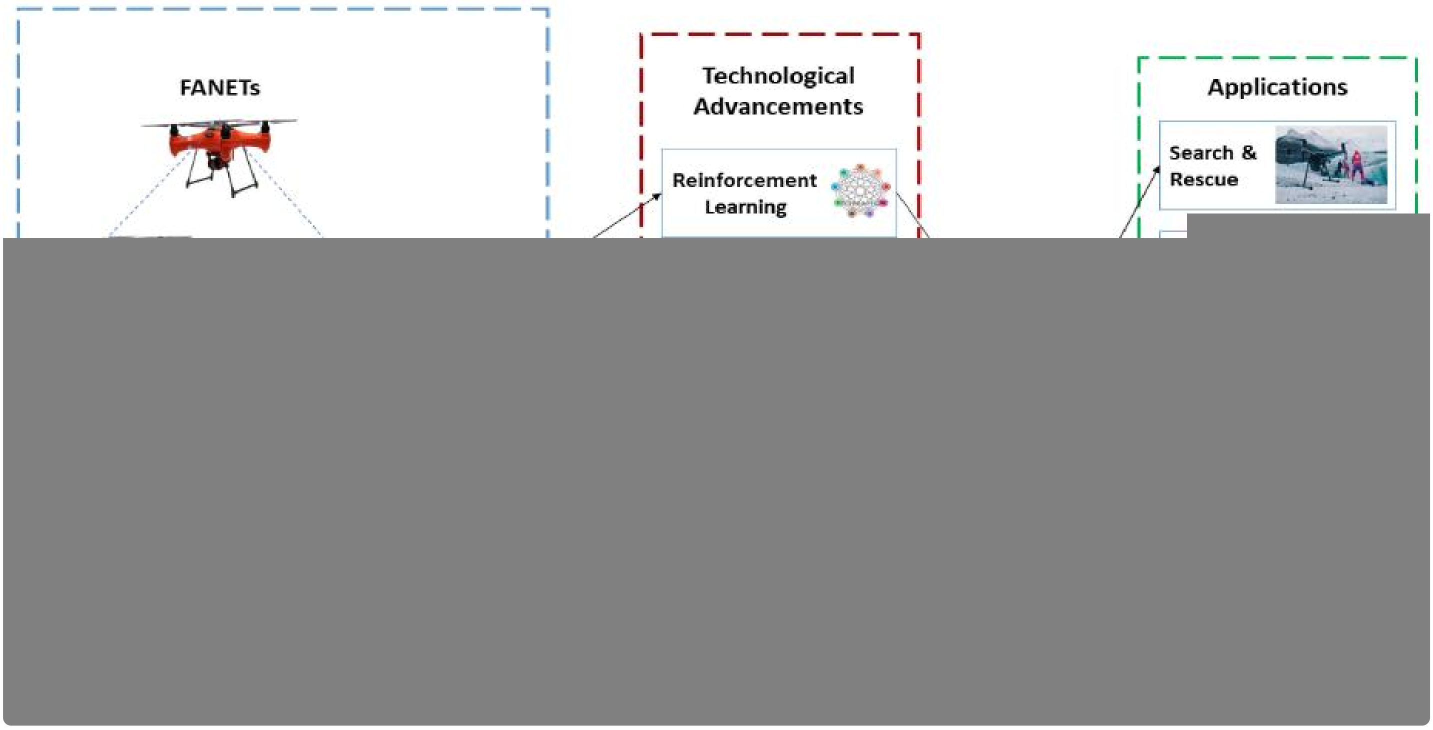
UAVs, FANETs, Communication Technologies

1. Introduction

Unmanned aerial vehicles (UAVs) have gained recognition for their variety of applications in different domains such as surveillance, agriculture, health care, traffic control, inspections, and public safety [1]. Moreover, in comparison to a stand-alone UAV, multiple small UAVs can be effectively combined to execute assigned tasks in autonomous ways [2]. Thus, advancing from a single UAV to multi-UAVs results in the emergence of a new clan of networks named flying ad-hoc networks (FANETs) [3]. Smaller interconnected UAVs can exchange data with each other and with base stations (BS) in a FANET system [4]. FANETs possess advanced features such as high mobility, fast deployment, self-configurations, low cost, scalability, and others. However, such specific features demand a set of guidelines that need to be addressed for effective implementation. Particularly, when selecting a FANET system for real-time communication, Quality of Service (QoS) should be guaranteed [5]. In addition, for the exchange of information between UAVs and a BS, the network must have incorporated an efficient and secure wireless connection.

FANETs can be deployed either individually or incorporated into traditional cellular infrastructures. The subject has attracted the interest of both industry and academic experts. Most related research studies seek to integrate FANETs with or without traditional networks in a manner that upholds the QoS, security, and reliability requirements of small UAVs [6]. Therefore, the detection and identification of vulnerabilities in the current systems are important for developing solutions that enable high-throughputs and reliable data communications. The popular short-range wireless networking technologies such as Wi-Fi (IEEE 802.11), ZigBee (IEEE 802.15.4), Bluetooth (IEEE 802.15.1), and others can be utilized to incorporate a FANET system independently. Such technologies not only provide wireless networking in the immediate vicinity, but also provide spectrum-free bands [7]. In the following two scenarios, they are a good choice: in the event of failure due to the deterioration of existing communication networks, and in remote areas, where problems do not enable installation and deployment immediately. Additionally, they can step up rescue operations by maintaining effective UAV communications. In addition, the low altitude of UAVs due to short-distance wireless communication significantly improves the performance of networks in terms of QoS.

The Fifth-Generation (5G) technologies are projected to offer improved services in terms of data rates and coverages in linking FANETs to existing cellular networks [8]. Moreover, 5G provides multi-access edge computing (MEC), incorporating cloud computing capabilities. MEC prevents resource-affected UAVs from performing compute-intensive tasks in a UAV environment and provides offloading facilities to the edge of the network. Hence, 5G has many benefits for high-altitude UAVs equipped with cameras, sensors, and GPS receivers. In addition, 5G has made it possible to envision cellular networks beyond 5G (B5G) and sixth-generation (6G) is capable of incorporating autonomous services as well as emerging developments to be envisioned [9]. The main issues are the safe usage of these technologies and the provision of privacy in small UAVs in future wireless networks. The design considerations of small UAVs rarely address the security concerns [10]. Small UAVs also suffer from security vulnerabilities due to limited and insufficient onboard computing and energy capabilities [11,12]. Such constraints prevent UAV deployment for longer periods of time and for safer operations. Significant attempts have been made to resolve the underlying technical problems in order to take advantage of the wider benefits of the multi-UAV networks [13]. Figure 1 shows a diagram summarizing the communication scope in FANETs, their involvement with recent technological advances, and their combined applications. Therefore, it is essential to have adequate wireless technologies and lightweight security schemes that can significantly stabilize battery life, have minimal computational costs, and encourage better connectivity. In comparison, in this review, key enabling technologies are addressed that manifest themselves as the paradigms needed to effectively deploy FANETs in the future. It also highlights the main challenges and provides guidance for future research work.



[redacted]

Figure 1. Scope of communication with technological advancements for various applications in FANETs.

The rest of the paper is organized as follows. Section 2 describes the key enabling wireless technologies; Section 3 elaborates on applications; in Section 4, the challenges are discussed; Section 5 highlights the future work, and finally Section 6 contains the conclusions.

2. Key Enabling Wireless Technologies

The choice of appropriate wireless communication technologies for FANETs depends on the type of an application and the nature of the mission involved. Unlicensed wireless technologies such as Wi-Fi, ZigBee, and Bluetooth are widely used for fast deployment and small- to medium-scale applications [6,7]. Licensed wireless technologies such as 5G/6G, on the other hand, are used to satisfy the requirements of broadband access everywhere, high device mobility, and integration of a massive number of UAVs in an ultra-reliable way [14]. Based on the spectrum type (licensed/unlicensed), the most suitable wireless technologies for FANETs are categorized in Table 1. To provide wireless connectivity in the immediate vicinity, unlicensed or short-range wireless technologies have the ability to offer off-the-shelf, lightweight, and cost-effective wireless connectivity. Unlicensed technologies offer information transfer in the instant vicinity ranging from millimeters to a few hundred meters.

The most suitable short-range wireless technologies are Wi-Fi, Bluetooth, and ZigBee, which can be used for medium and low data rate applications of FANETs. Wi-Fi provides a set of specifications for the implementation of wireless local area networks (WLANs) with radio bands of 2.4, 3.6, 5, and 60 GHz, respectively. IEEE 802.11a/b/g/n/ac is the first choice of variants for many FANET applications to provide the required throughput for transmitting medium size data such as video and images [15]. The standard Wi-Fi system has a transmission range of approximately 100 m. A multi-hop networking scheme may expand the transmission range to kilometers. However, it cuts down the lifetime of the network from hours to minutes. An alternative to Wi-Fi is the use of low-cost and low-power radios like Bluetooth and ZigBee. Bluetooth (IEE 802.15.1) is a possible candidate for the deployment of FANETs at low cost and low power manners. It operates in an unlicensed frequency band of 2.4 GHz with a contact range of 10 to 100 m and uses a distributed frequency-hopping transmission spectrum. Bluetooth technology, with data rate ranging from 1 to 3 Mbps and a capacity of 24 Mbps, can be used in three different models. The new version of Bluetooth core specification is Bluetooth 5 [16]. The primary focus of Bluetooth 5 is to improve data rate, coverage, energy efficiency, and coexistence with other technologies. Given the major improvements, Bluetooth 5 appears to be a possible candidate for implementing future FANET systems at low cost and low power manners. Similarly, ZigBee technology is widely used in applications that require long battery life, low data rates, and secure networking. It ranges from 10 to 100 m and is less expensive and convenient than proprietary communication technologies such as Bluetooth and Wi-Fi.

Low-power wide area networks (LPWAN) can be another good option that consumes less energy and offers a wide range of connectivity for UAVs [17–20]. LPWAN allows transmitting data for a longer duration of time and without much loss of energy resources. LoRaWAN has been designed as a convention explicitly for the management of low energy consumption transmissions when Internet of Things(IoT) devices on LPWAN [21,22]. For IoT users, LoRaWAN uses a novel network paradigm for bidirectional connectivity, localization, and mobility management services [23]. It provides a new framework for LPWAN execution for long-range communications. It has the potential to operate over the ISM band (868 MHz and 900 MHz) with data rates ranging from 0.3 kbps to 50 kbps and network coverage from 05 to 15 km [24–26]. Sigfox, similar to LoRaWAN, is a low-speed but low-power and long-range solution for UAVs. It uses the same ISM band as LoRaWAN. One of the advantages of Sigfox is that it supports open-sight up to 30 km of range.

If the unlicensed wireless technologies are not capable of meeting the UAV throughput requirements, traditional cellular communications can be used as a backhaul for providing data transmission services in two sights. Narrow band Internet of Things (NB-IoT) is a LPWA standard technology designed to provide connectivity and access to new services for a wide range of the latest IoT devices. NB-IoT, especially in deep coverage, significantly improves user device power consumption, system capacity, and spectrum efficiency. Moreover, as the later proposals in 5G have made it conceivable to conceptualize cellular systems beyond 5G (B5G) and sixth-generation (6G), able of unleashing the complete potential of copious, past-including autonomous administrations as well as emerging trends. They give capacity extension methodologies to resolve the issue of gigantic connectivity and give ultra-high throughput, indeed in extraordinary or crisis circumstances where there may be shifting framework densities, transmission capacity as well as traffic pattern. These technologies can moreover be valuable to FANETs by empowering UAVs to communicate specifically with each other and at the same time with a fixed communication framework. Within the same setting, the limited onboard processing capacity of small UAVs, storage, and battery imperatives raises a number of concerns over the effective execution of complex assignments. Leveraging the cloud storage facility offered by 5G to offload both computation and storage-intensive activities from resource-constrained UAVs to remote cloud servers is an effective technique to overcome these limitations. Furthermore, the deployment of UAVs as a flying base station (BS) with other physical layering mechanisms such as massive MIMO, cognitive radios, mmWave, and others as a prerequisite, is a promising approach to achieve data-hungry services [27].

The above discussions led to the conclusion that depending on the range and throughput requirements, Bluetooth, ZigBee, Wi-Fi, LoRaWAN, and Sigfox can be considered, depending on the range and throughput requirements [28]. 5G and 6G can be a more suitable choice if the coverage area is large, together with high throughput demands. However, these technologies require the existing telecommunications infrastructure.

Table 1. Comparison between the various communication technologies for FANETs.

Communication Technology	Standard/Service Category	Spectrum Type	Frequency/Medium	Device Mobility	Theoretical Data Rate	Range Indoor-Outdoor	Latency
Wi-Fi	802.11	Unlicensed	2.4 GHz IR	Yes	Up to 2Mbps	20–100 m	<5 ms
	802.11a	Unlicensed	5 GHz	Yes	Up to 54Mbps	35–120m	
	802.11b	Unlicensed	2.4 GHz	Yes	Up to 11Mbps	35–140m	
	802.11n	Unlicensed	2.4/5 GHz	Yes	Up to 600Mbps	70–250 m	
	802.11g	Unlicensed	2.4 GHz	Yes	Up to 54Mbps	38–140 m	
	802.11ac	Unlicensed	5 GHz	Yes	Up to 866.7Mbps	35–120 m	
ZigBee	802.15.4	Unlicensed	2.4 GHz	Yes	Up to 25Kbps	10–100 m	15 ms

Bluetooth V5	802.15.1	Unlicensed	2.4 GHz	Yes	Up to 2Mbps	10–200 m	3 ms
LoRaWAN	IEEE 802.15.4g	Unlicensed	868 MHz, 915 MHz	Yes	Up to 50 kbps	05–15 km	Device Class Dependent
Sigfox	-	Unlicensed	868 MHz, 902 MHz	Yes	Up to 100 bps	03–30 km	2 s
NB-IoT	· LTE Cat NB1 · LTE Cat NB2	licensed	200 KHz	Yes	Up to 250 kbps	10–35 km	1.6–10 s
5G	· mMTC · URLLC · eMBB	licensed	· Sub-6 GHz · MmWave for fixed access	Yes	Up to 1 Gbps	Wide Area	1 ms
B5G	· mMTC · URLLC · eMBB · Hybrid (URLLC + eMBB)	licensed	· Sub-6 GHz · MmWave for fixed access	Yes	Up to 100 Gbps	Wide Area	1 ms

6G	· MBRLLC · mURLLC · HCS · MPS	licensed	· Sub-6 GHz · MmWave for mobile access · Exploration of higher frequency and THz bands (above 300 GHz) · Non-RF (e.g., optical, VLC, etc.)	Yes	Up to 1 Tbps	Wide Area	<1 ms

3. Applications and Feasibility of the Wireless Technologies

The use of small UAVs for multiple insurgents, civilian, and commercial applications is expected to produce good results when it comes to providing accurate and reliable data transfer. As shown in Figure 2,some of the areas where FANETs can be used are search and rescue, mail and delivery, traffic monitoring, precision agriculture, reconnaissance, and others.

3.1. Search and Rescue (SAR)

SAR missions are amongst the most popular aerial robotics driving applications. This is largely due to UAVs' unique features such as versatility, flexibility, and scalability in contrast with human vehicles [29]. Furthermore, the UAVs are able to fly autonomously, access difficult terrain, and perform tasks of data collection, which are impossible for human vehicles. The advent of FANETs has further increased UAV participation in active search and rescue operations [30]. In the event of unexpected natural disasters, hazardous gas intrusions, wildfires, avalanches, and the rapid identification of missing persons, FANETs will serve as the first line of protection. In such scenarios, FANETs could be deployed in the affected areas, in exchange for sending humanitarian aid that could be at risk. UAVs were first used during the 2005 Hurricane Katrina search and rescue missions and later in the 2011 Fukushima and 2015 Nepal earthquake, respectively [31].

In [32], the authors proposed a modern search and rescue operations (SARO) strategy to search for survivors following major disasters on the assumption that wireless communication network cells are partly functional while taking advantage of the UAV-based network. These SAROs are based on the notion that nearly all survivors should be equipped with handheld remote gadgets called User Equipment (UEs), which function on the ground as human-based sensors. The control messages in SAR operations include the exchange of task assignment, position and heading, and map information, while the data messages involve either images or video streaming, requiring a minimum data rate of 1 Mbps and 2 Mbps, respectively. In addition, the delay limits for these operations is about 50 ms and 100 ms and covers small- to medium-sized areas. Thus, keeping these parameters in mind, unlicensed (i.e., Wi-Fi and Bluetooth 5) technologies can be used for limited coverage areas and a fewer number of nodes, whereas cellular technologies can be used for large coverage areas and mass deployment of UAVs.

3.2. Mailing and Delivery

Package delivery is one of the most enticing UAV applications supported by major courier companies for quick, cost-effective and efficient transportation of packages that weigh less than a UAV maximum bearing load [33]. For example, Amazon reports that 83 percent of its packages weigh less than 2.5 kg [34], while the average FedX package weighs less than 5 kg [35]. Moreover, the adoption of UAVs is increasing rapidly due to the growing trend of online ordering in congested cities, especially in the retail sector. Many major retailers and logistics companies are stepping up efforts to integrate small UAVs into their transport systems to solve the problem of “last mail” delivery. The authors in [36] illustrated the plans of large retailers and logistics companies as follows: DHL launched its drone delivery service for express and emergency products and began the first automated drone delivery to Juist Island in 2014; later on, DHL successfully made more than 100 deliveries in the Bavarian Alps in early 2016 through its Parcelcopter 3.0 drone; UPS tested the delivery of a successful automated drone in Florida in 2017 from the roof of a company electric vehicle; and through securing a U.S. patent, Amazon created major competition to legalize its UAV distribution project called “Prime Air.” Patent and Trademark Office are dropping packages from drones to consumers through the use of parachutes.

Mailing and delivery operations require low throughputs for trajectory planning, however, the coverage areas may be large. The communication range of unlicensed technologies is limited, so it is therefore possible to use any appropriate licensed technology for mailing and delivery operations.

3.3. Traffic Monitoring

Roadway traffic surveillance is also a possible application where FANETs can replace the laborious and complex infrastructures used for observations. UAVs are less costly than traditional traffic control devices used on the roadside such as loop detectors, video surveillance cameras, and microwave sensors [37]. Moreover, data obtained from detector technology is somewhat statistical in nature and does not provide precise tracking of the individual vehicle path within the stream of traffic. It limits the use of data obtained in the study of calibration, human driving behaviors, and simulation models [38]. Additionally, disasters can easily damage the fixed structures located along the road side used for computing, communications, and electrical systems. Such shortcomings result in a complete lack of the transport network capacity to track and gather data [39]. Alternatively, the FANETs that can track and record accidents or perform traffic management statistics are an economically and socially viable choice because of their 3D movement, high speed, and wide coverage.

In traffic monitoring, UAVs are involved in transmitting images and video streaming to the control center in real-time; thus, licensed technologies will be a better choice. In addition, licensed technologies make use of existing communication infrastructures, particularly in urban areas and can operate without line-of-sight.

3.4. Precision Agriculture

Management of agriculture production includes the monitoring of crop health. Despite manned aerial vehicles having been used in this sector over the decades, however, the new concept of autonomous UAVs is considered more beneficial as they conduct field operations with greater precision on smaller as well as wider fields [40]. High-resolution crop images can be taken with the aid of small UAVs. The captured images are processed in order to produce relevant information, which can then be used for future decision-making. Crop health is defined using data obtained from the color imaging mapping of the normalized vegetation difference index (NDVI) [41]. These color images are usually obtained through a multispectral high-definition camera installed on the UAVs. NDVIs are counted as separating healthy from unhealthy plants, which is achieved by calculating the level of chlorophyll in crops. It takes advantage of the knowledge to identify the area under greater stress. The decision support engine (DSE) is responsible for taking the appropriate steps to process the task.

The coverage area in precision agriculture can be small or medium in size. Short-range wireless technologies, particularly Wi-Fi, can be the most appropriate choice to meet the requirements in terms of coverage, latency, and throughput in crop health monitoring.

3.5. Reconnaissance

For a long time, UAVs have been used for surveillance applications. However, with the advent of FANETs, the idea of surveillance is supposed to be more revolutionized. UAV plays a key role in reducing human intervention in patrolling a particular geographic location. Aerial surveillance tasks may involve collecting battlefield information, mapping areas affected by earthquakes, and monitoring law enforcement activities. Taking photographs of items distributed over large regions and areas of interest can also be used in surveillance work. For example, a border surveillance UAV group can detect not only unplanned humanitarian problems including weapons and drugs, but illegal border crossings [42]. The collected information can then be analyzed and transferred directly to the Intelligence Control Centers. However, data sensitivity calls for high precision and accuracy for immediate intervention. All such surveillance missions are complex in nature and are usually intolerant to false alarms.

Similar to search and rescue operations, in reconnaissance, unlicensed (i.e., Wi-Fi and Bluetooth 5) technologies can be used for cases of limited coverage areas and fewer number of nodes connectivity, whereas licensed technologies can be used for large coverage areas and mass deployment of UAVs.

Figure 2. Advantages, key wireless technologies, applications, and challenges of flying ad-hoc networks.

Retrieved from https://encyclopedia.pub/entry/history/show/6562