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Unmanned aerial vehicle: a review and future directions

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ABSTRACT

The use of unmanned aerial vehicles (UAVs) will be crucial in the next generation of wireless communications infrastructure. When compared to traditional ground-based solutions, it is expected that their use in a variety of communication-based applications will increase coverage and spectrum efficiency. In this paper, we provide a detailed review of all relevant research works as follows. This paper presents types of UAVs (e.g., wireless coverage, military, agriculture, medical applications, environment, and climate, and delivery and transportation), characteristics of UAVs (e.g., node density, altering system topology, node mobility, radio broadcasting mode, frequency band, localization, and power consumption and network lifetime), the application of UAVs (e.g., Multi-UAV cooperation, UAV-to-VANET collaborations, and UAV-to-ground tasks). Additionally, this paper reviews the routing protocols of UAVs (e.g., topology-based, position-based, heterogeneous, delay-tolerant networks (DTNs), swarm-Based, and cluster-based) and simulation tools (e.g., OMNeT++, AVENS, MATLAB, NS3, SUMO, and OPNET). The design and development of any new methods for UAVs may use this work as a guide and reference.

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1. INTRODUCTION

Due to their improved stability and endurance in many missions, unmanned aerial vehicles (UAVs), often called drones, have garnered significant contributions in various civilian and military service disciplines [1]-[3]. UAV uses are developing significantly as a result of their cutting-edge utilization in the internet of things (IoT) and fifth-generation [4]. Over the past ten years, UAVs have been used for many different purposes, such as item prevention and tackling, general security, road surveillance, military application, a search of hidden or serious regions, within-door or out-door navigation, aerial tracing, post-disaster application, e-hospital, message changing, infrastructure administration, contingency, and crisis administration, load transport, logistics and wildfire controlling [5]-[8].

Unmanned aerial vehicles (UAVs) are a type of pilotless aircraft that can take to the air and stay there without the help of a live person. They have a wider range of uses and are less expensive than manned frameworks in many situations [9], [10]. UAVs can be piloted from afar with the help of a ground-based control station (BS) and a remote power source. Self-control of UAVs is possible via autopilot and various sensors like global positioning systems and inertial measurement units (IMU) [11]-[13].

Particularly prominent e-commerce giants like Amazon, Google, DHL, and Walmart have invested heavily in UAV technology [14], [15]. The rise of e-commerce has resulted in an increase in demand for expedited shipping options, which could have a major effect on consumer spending. As a result, e-commerce firms are investigating options to expedite shipping. On the flip side, retailers have a serious challenge in terms of providing last-mile delivery that is both cost-effective and efficient [16]-[18].

With their rapid and creative designs that guarantee last-mile delivery while being ecologically friendly, UAVs have emerged as viable solutions in this field. UAVs have many advantages, including quick and simple deployment, scalability and flexibility, self-organization, cost-effectiveness, and great maneuverability [19]-[22]. To carry a variety of payloads, such as communication devices, navigational aids, sensors, and cameras, UAVs come in a wide range of configurations, sizes, weights, ranges, and performance traits. UAVs can be divided into numerous categories based on features, including arrangement, engine kind, weighting, domain, and extent [23]-[26].

Nevertheless, a number of significant issues severely restrict UAV performance. Restriction of motion, restricted autonomy, and limited flight time are all examples of such constraints. Factors such as sensor accuracy, difficult weather, the size of the fixed-wing aircraft, and battery life all contribute to a short flight time. Multiple UAV vulnerabilities enhance the likelihood of being subjected to malicious attacks [27]-[29]. A number of works have been conducted to evaluate the UAVs' weaknesses, threats, and attacks, and they have offered workable methods to address these issues, such as the use of high-quality components, including motors, wings, batteries, and manufacturing materials. According to several studies, UAVs can discover the shortest route to their destination by using optimization algorithms [30]-[32].

Several start-up companies have emerged to meet the rising demand for agricultural UAVs on the market. Price-waterhouse-coopers predicts that the market for agricultural UAVs will reach $32.4 billion by 2050, making up about 25% of the global UAV market (see Figure 1 for more details) [33]. Some of the most well-known UAV manufacturers are DJI, Parrot, Precisionhawk, AGEagle, and trimble navigation. Although many unmanned aerial vehicles (UAVs) have been developed and brought to market, there are still issues that need fixing before they can be used effectively in agriculture [34].

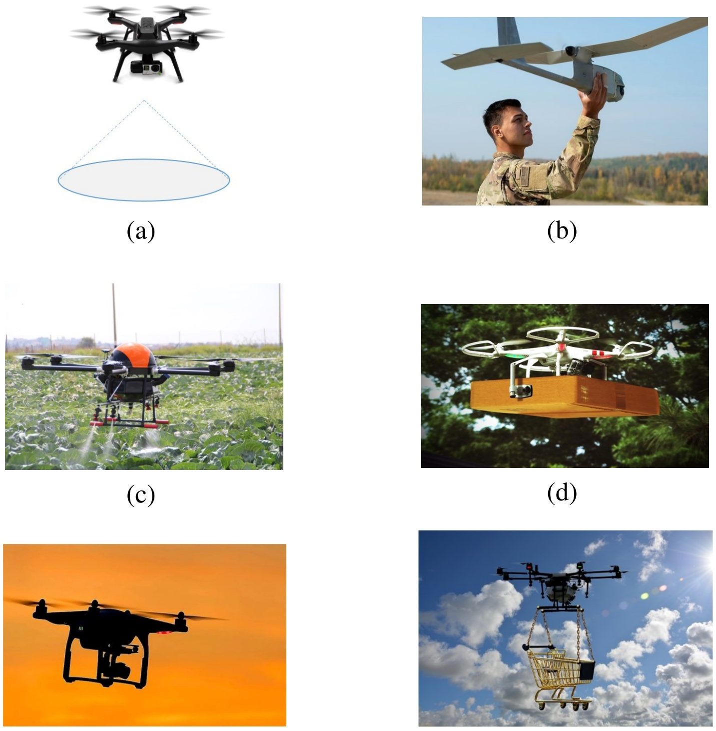
Top-tier innovations can be found in areas like precise positioning, navigation, controls, imaging, communications, sensors, materials, batteries, circuits, and motors. Some technologies (e.g., equipment development, nozzle controls, and big data) are necessary for UAV use, depending on the nature of the farming industry and the specifics of the UAV's mission. It isn't easy to provide comprehensive details on all UAV technologies. Therefore, this review paper aims to provide a deep understanding of the types of UAVs, the characteristics of UAVs, the application of UAVs, and the routing protocols of UAVs. Meanwhile, this paper presents simulation tools and the future directions of this paper.

The remainder of this work is arranged as follows. Section 2 shows types of UAVs. Section 3 presents characteristics of UAVs. Section 4 presents the application of UAVs. Section 5 presents routing protocols of UAVs. Section 6 presents simulation tools. Section 7 presents the future directions of this paper. Finally, section 8 concludes this paper.

2. TYPES OF UAV

This section classifies UAVs according to their application used. The type of UAV chosen for a given purpose must satisfy a number of criteria, including energy capacity, endurance, payload, and adherence to local laws. As shown below, Figure 1 shows a number of UAV types that can be used for classification. Figure 1(a) shown UAV as wireless coverage: directional antenna-equipped UAVs are employed to offer wireless communication for both outdoor and indoor customers in crowded areas or when worldly BSs are unavailable due to inclement weather [35], [36]. Figure 1(b) shown type of UAV as military: defense forces all around the world are using UAVs more frequently for a set of purposes, such as vulgarity, monitoring, network, attacks, and warfare as a result of ongoing developments in UAV technology [37]. Figure 1(c) shown UAV use in agriculture: UAVs are able to plant seeds and seedlings, harvest crops, and look for weeds and pests. They could drizzle crops more precisely than a regular bulldozer can as well [38]. Figure 1(d) shown UAV purposed to medical applications: UAV use has started to spread among emerging medical fields. When an unexpected natural disaster strikes, they are utilized for search and rescue, for the delivery of drugs, first aid supplies, and lab samples, as well as for remote telemedicine and teleradiology services [39]. Figure 1(e) shown UAV use in environment and climate: UAV applications in the mining industry [40], animal conservation [41], forest fire detection [42], and many more uses are all ways that UAVs can be utilized to benefit the environment.

Figure 1(f) shown UAV purposed to delivery and transportation: delivery food, medical supplies, household goods, packages, and ship resupply can all be transported with UAVs [43].



(a) (b) (c) (d) (e) (f)

Figure 1. Types of UAV: (a) wireless coverage, (b) military, (c) agriculture, (d) medical applications, (e) environment and climate, and (f) delivery and transportation

3. FEATURES OF UAV

As presented in Figure 2, the major features of UAV are node consent, altering system topology, node mobility, radio propagation model, frequency band, localization, and power consumption and network lifetime [44], [45], as the following described. Node density: the density of node is the middle amount of UAVs per size. In comparison to other ad hoc networks like MANET and VANET, FANETs have a lower UAV node density. Depending on the goal of the UAV's mission, the node density can be changed. Changing network topology: due to the UAVs' quick movements, UAV network topologies frequently change. Under conditions of frequent topological fluctuation, possible FANET topologies include mesh and star topologies, where dynamic routing is required, and all UAVs directly communicate with the ground control station (GCS) [46], [47]. Mobility of node: one of the key characteristics of UAV is node mobility, which is much higher than that of VANET and MANET. Depending on the type of UAV, UAV speeds range from 30 to 460 km/h. This may result in problems such as interruptions, link failure, and more. Radio propagation model: any simulation or design of a communications system must include the network's radio propagation model. The most common and straightforward simulation model used in extensive simulations is the Friis free space model. Frequency band: UAV communication systems frequently employ unlicensed bands like 0.9 GHz and 2.4 GHz. Congestion may result from the use of these bands, though. The best results for UAV-to-Ground communications come from combining 5 GHz with IEEE 802.11a. Localization:b ecause UAVs are fast and mobile and cause changes in network topology, FANETs use low-latency global positioning (GPS) to find them. Energy use and network lifetime: energy restrictions are a serious problem for ad hoc networks. The volume of the UAVs, the travel distances, the FANET's network technology, the link, and other obstacles all affect how much power is used in FANETs [48].

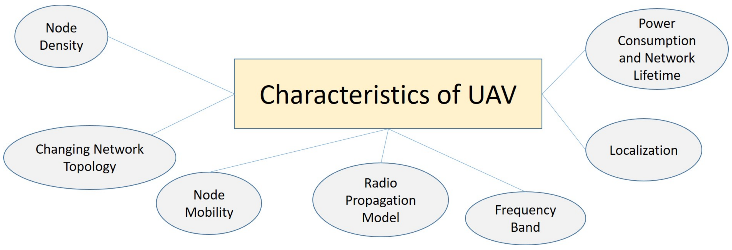


Figure 2. Characteristics of UAV

4. APPLICATION OF UAV

As shown in Figure 3, UAV has three primary applications that can be separated. The name of these applications as Multi-UAV cooperation, UAV-to-VANET collaborations, and UAV-to-Ground tasks. The description of these applications is provided as follows.

Multi-UAV cooperation: i) Situations of emergency:UAVs are employed in the building sector to assess the safety and track the development of structures. In many other emergency situations, as well as during emergencies where terrestrial base stations are down, UAVs can be utilized to temporarily extend wireless covering in cellular systems [49]; ii) Tracking and monitoring in disaster situations: UAVs can assist in determining the direction that a flood is moving and then forecast which buildings will be at risk of damage. Similar to this, they can be used for rescue efforts following earthquakes, recognizing collapsed buildings with a high concentration of people, such as hospitals and schools, in order to give these locations a higher priority in rescue operations [50]; iii) Target detection: UAVs can use target detection technology like thermal and vision cameras to find people and objects [51].

UAV-to-VANET collaborations: i) Route guidance: due to the great mobility of the vehicles in VANETs, routing is insufficient. In VANETs with UAV assistance, multi-hop relays are used to transport data between vehicles and UAVs. In VANETs, UAVs are utilized to improve routing and give route guidance [52]; ii) Data packet delivery: according to the paradigm of load-carry-and-delivery (LCAD), which involves using numerous UAVs, data is filled from the origin user and transmitted to the specialization user by UAVs, UAVs deliver packet data [53]; iii) Roadway traffic monitoring: use of UAVs is much quicker than sending in the incident commander's car. Additionally, UAVs can be used to improve road safety by recording real-time recordings of various security events and situations in road networks[54].

UAV-to-ground tasks: i) Search and rescue missions: UAVs are essential for search and rescue operations (SAR). FANETs are thought to provide a huge advantage in ensuring public SAR missions, safety, and handling natural or man-made critics such as terrorism, overflow, cataclysm, forestry fires, and tsunamis, and checking the security of vital infrastructure, including utilities like force and sea; and ii) public and civilian applications: due to their advantages over ground-based infrastructure in terms of flexibility and cost, UAVs have been very deployed in a crowd and civilian area applications, particularly in the shape of little quadcopters.

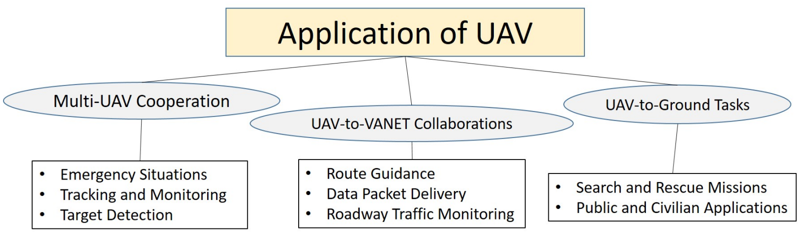


Figure 3. Application of UAV

5. ROUTING PROTOCOLS OF UAV

Various groups of routing protocols at the layer of the network are presented for UAVs in this section. Figure 4 shows one potential classification of UAV routing protocols. The description of these routing protocols is provided as follows. Topology-based: topology-based hop-by-hop routing protocols use link-state information like IP addresses and network topology information to help senders route packets in the most efficient way possible [55]. Position-based: these protocols use reactive, predictive, greedy [56], [57], and hierarchical [58] techniques to determine the transmitter and receiver's positions in advance utilizing the geographic information of the nodes known from GPS. Heterogeneous: different ground systems, such as MANETs, VANETs, or stationary users, with which FANETs communicate, require varied routing protocols in order to exchange data between moving users. In FANETs, both mobile and fixed nodes can be supported using routing protocols with heterogeneous approaches [59]. Delay-tolerant networks (DTNs): the mobile nodes in DTNs are sporadically and erratically connected. In order to handle the DTN features, new routing protocols are required because mobile nodes have high latency and low data throughput [44]. Swarm-based: this routing method uses fish, bird, and insect social behavior to discover the best path and topology management strategy [60]. Cluster-based: nodes with comparable traits and properties are merged to form clusters in the clustering approach. Each cluster has a cluster head, which handles communication processing [61].

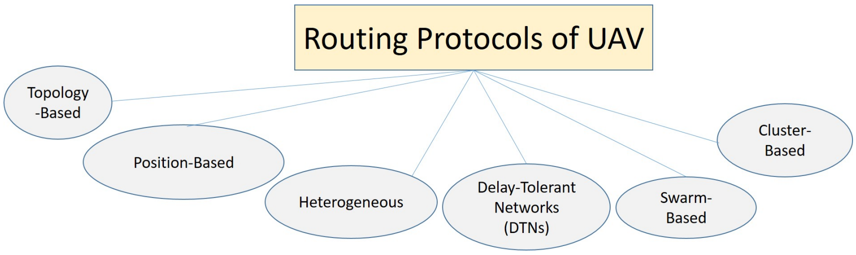


Figure 4. Routing protocols of UAV

6. SIMULATION TOOLS

The process of assessing the effectiveness of the UAV-enabled system in the actual universe is challenging and takes a significant amount of time and money. The top class of mobility of the UAVs and the frequent topology changes makes it difficult, expensive, and time-consuming to evaluate UAV performance practically. Additionally, many forms of cyber-attack resistance estimation testing for UAV networks are prohibited due to rules surrounding the use of UAVs in the majority of nations [62]. Consequently, a variety of adaptable simulation tools have been created to enable the creation, construction, testing, and evaluation of schemes virtually without the need for practical application. The available FANET performance study tools include OMNeT++, AVENS, MATLAB, NS3, SUMO, and OPNET. Additional information on each simulator is provided in Table 1.

Table 1. UAV system performance study simulation tools

Name	Programming language	Mobility model	Operating system
OMNeT++	C++, high-level language (NED)	Flight plan (FP), random waypoint (RWP), random walk (RW)	Linux, MacOS. and Windows
AVENS	N/A	Linear mobility	Linux, Windows, MacOS
MATLAB	C, C++	Semi-random circular movement (SRCM), particle swarm mobility model (PSMM)	Windows, Linux, and MacOs
NS3	C++, with an OTcl interpreter	Random walk (RW), random waypoint (RWP), Gauss Markov (GM), reference point group mobility model (RPGM)	Linux, Windows, MacOs
SUMO	C++, Python	N/A	Windows, Linux or MacOs
OPNET	C, C++	Random direction (RD), random walk (RW), random waypoint (RWP), group mobility	Red Hat, Windows and CentOS

- OMNeT++: a component-based network simulator that uses the Windows language (NED) and is modular, extendable, and used both for academic and commercial applications.
- AVENS: a simulator-based control of flight that integrates co-simulation among modeling simulations using OMNeT++/INET and the XPlane flying simulator drone communication
- MATLAB: the capability to incorporate ML/AI with its docile and ML Toolbox, a UAV Toolbox, and

various sample applications using both fixed-wing and multirotor UAVs are also provided.

- NS3: both IP and non-IP networks can be simulated. The effectiveness of TCP and mobile ad hoc networks can be evaluated using it.
- SUMO: it can be combined with OMNeT and NS3, but since it is designed for 2D vehicles, it cannot be used directly in FANETs.
- OPNET: offers a strong graphical user interface with animated graphics considerable expenses.

7. FUTURE DIRECTIONS

The problems with UAVs that were discussed earlier have been the subject of numerous proposals for acceptable solutions, but there are still many problems that need to be solved. This section discusses the future direction of UAVs. The following points are provided in detail.

- There are a number of advantages for different collaborative areas provided by collaborative UAV technologies; however, there are a number of issues that need to be resolved.
- Energy-efficient algorithms must be developed for various elements, including cooperative communication, sensing, processing, actuating, and data storage due to the energy limits of UAVs [63].
- Another difficult problem in UAV-assisted technologies are providing effective resource management techniques that attempt to dynamically make purse including bandwidth, broadcasting power, the number of UAVs, and its flight time.
- Given that UAVs are now frequently employed in communications, including domains (military, emergency services, and infrastructure search) that contain critical data, providing security in UAV-enabled communication is a challenging task. Therefore, reliable and secure communications and services in UAV-related technologies need to be provided through the use of efficient methods.
- The flexibility of a UAV's deployment depends on its mobility and its ability to fly to its destination and complete its mission. UAVs' ability to react and state their mobility in real time is critical for conflict avoidance and power management.

8. CONCLUSION AND FUTURE WORK

UAVs are used in a wide variety of applications nowadays. The applications of these systems are only briefly discussed in a small number of highly specialized research articles. By offering a general overview of the various uses of numerous UAV systems that have been created recently, this survey seeks to close this gap. This paper presents the types of UAVs, the characteristics of UAVs, the application of UAVs, the routing protocols of UAVs, and simulation tools. Additionally, we present the future directions of this paper. In future work, we will propose a scheme based on UAV to secure the VANET communication system in order to prevent any attacker as well as decrease the overhead of the system in terms of communication and computational costs.

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