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Investigation on Unmanned Aerial Vehicle (UAV): An Overview

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Abstract

Unmanned Aerial Vehicles (UAVs) are becoming increasingly popular these days. One among the major technological developments of today are UAVs or drones. The coordination and coverage capabilities of large clusters of UAVs, or their cooperative capabilities for such goals as terrain mapping, make them of particular interest. This paper explores the use of unmanned aerial vehicles in smart and modern cities in depth. Future wireless networks will likely include UAVs to facilitate wireless broadcasting and support high-speed transmissions. Various layer techniques are discussed in this paper. Moreover, an overview of the latest UAV communication technologies and network topologies has been presented. Military and commercial applications have attracted a lot of interest in unmanned aerial vehicles. Due to their low cost and flexible deployment, UAVs are considered valuable in 5G and 6G networks due to their communication capabilities. Like aerial base stations, relays, or mobile users in cellular networks, UAVs can provide airborne wireless coverage in a variety of ways. Wireless links can only be established temporarily with UAVs. A great challenge is to extend UAV communication's lifetime and develop low-power, green UAV communication. A comprehensive study of green UAV communications has been presented in this paper. Furthermore, an overview of UAV applications is also illustrated. Additionally, some promising research topics and methods are being discussed.

Keywords: Energy efficiency, 5G, 6G, UAV, Wireless networks, communication, Base Station, D2D, NOMA, mmWave

1. Introduction

Technology improves very rapidly in the area of mobile communications and wireless technologies every day [1]. A reliable, secure, and efficient 5G service will have to meet

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major challenges [1]. The research into 6G networks must begin even though 5G technology hasn't yet been fully implemented [1]. Researchers and network designers are compelled to research possible solutions in order to understand whether high data rates, wide radio coverage, and a colossal number of connected devices can address these fundamental issues [1]. Using intelligent and efficient technologies will make it easier to develop 5G wireless networks [1]. In contrast to conventional aircraft, UAVs have no operators onboard. Consequently, they are capable of being operated either remotely or autonomously.

The four main types of UAVs are rotorcrafts, fixed-wing aircraft, flapping-wing aircraft, and hybrid aircraft. Considering the wide range of uses UAVs cover, from simple hobby drones to military remotely controlled aircraft, it is not surprising that interest in UAVs has grown so quickly. Aerial photography is one of the most popular uses for UAVs, which is useful for many tasks, such as precision agriculture, security monitoring, and disaster intensity monitoring. Both academia and industry find UAVs to be extremely useful in several areas. Scientists and engineers are thus becoming increasingly eager to push these robots to their limits in terms of performance and capability. Drones have significantly improved in airframe design, flight control, propulsion systems, and energy management through the efforts of many scientists and engineers. The recent multiagent control algorithms are ideal candidates to be tested on UAVs. Numerous real-life applications of UAVs include payload delivery, traffic monitoring, moving objects in potentially hazardous environments, and surveillance.

It is necessary to plan feasible and optimal trajectories for the movement of UAVs when employing them for any of these uses. It is nearly impossible to map out the configuration space where UAVs are flying as they may react dynamically to flying objects or static objects in their flight paths. In fact, the configuration space cannot be fully mapped out for UAVs, so global path planning becomes nearly impossible for them.

UAV works same as like of drones as they find their way on its own, has led to further growth in their market share among consumers. Researchers are now focusing significant research efforts on communication problems related to drones and how to remedy them. Due to the lack of physical infrastructure, drones enable us to reach areas that are difficult to access. Therefore, drones are increasingly used in various fields, such as forestry, agriculture, environmental protection, and security and for critical operations like rescue, surveillance, and transportation. The drones were once operated independently, but today, many of them are synchronized and perform operations together [2]. Drone communications become critical in these situations. UAV communication should be understood from various perspectives. The communications of drones, however, take advantage of a variety of wireless channels and networking protocols. As a result, a UAV network's communication method is determined by its application.

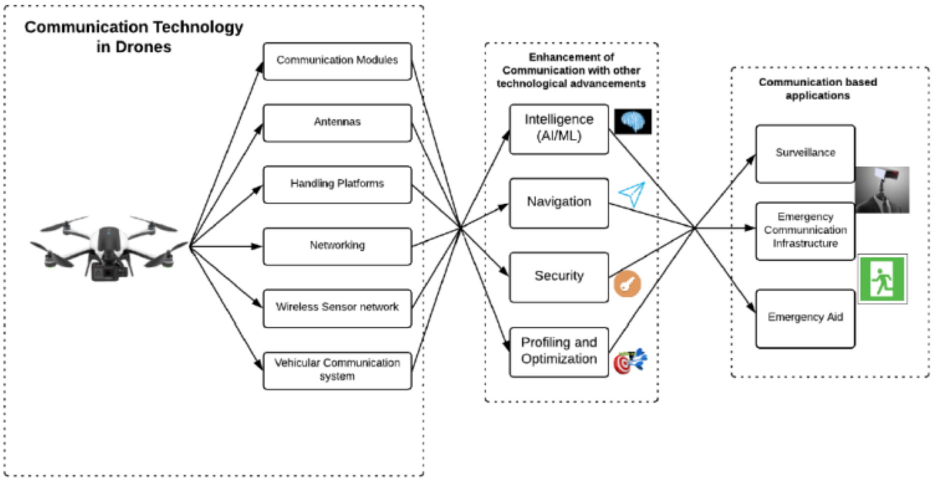

Figure 1. Technology used in drone communication

This paper is structured as follows: Methods for the physical layer and the network layer are described in section 2. In section 3, communication and network technologies for UAVs are illustrated. Section 4 explains the types and energy consumption models of UAV. Section 5 discusses UAV applications. In section 6, the challenges of UAVs are given. Finally, this paper is concluded in Section 7.

2. Physical Layer and Network Layer Methods

2.1 Physical Layer Methods

There is currently a wide range of research relating to UAV-assisted communication systems, specifically those related to emergencies or temporary events [3]. By using portable transceivers and advanced signal processing techniques, UAV communications can provide omnipresent coverage and enable massive dynamic connections. Fig. 2 depicts UAVs in the role of flying Base Stations (BSs), which have a variety of payloads capable of receiving, processing and transmitting signals, providing additional capacity to hotspots during temporary events in addition to the pre-existing cellular systems. Future cellular networks will be facing likely scenarios based on this scenario [4]. It is also possible to employ UAVs for construction and maintenance of communications infrastructure when the current terrestrial network is damaged or not fully functional in emergency situations [5]. The physical layer techniques are of great concern given the serious impact they have on UAV applications in 5G networks, which will drastically improve system performance.

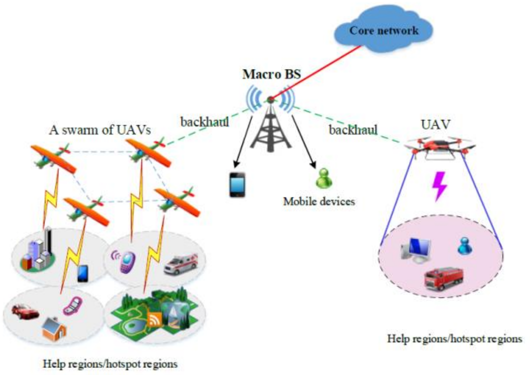

Figure 2. An aerial BS scenario for UAVs in target areas

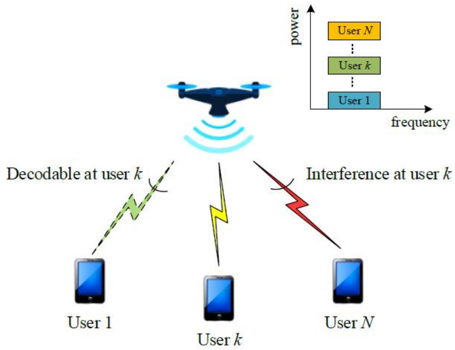

Figure 3. A scenario for UAV NOMA

2.1.1 mmWave UAV

Due to the considerably shorter wavelength, mmWave has its own unique fundamental characteristics compared to the sub-6GHz band [18]. To develop 5G/6G wireless systems, it is essential to have a reliable and accurate understanding of mmWave channel propagation characteristics [18]. mmWave links are directional by nature. Atmospheric attenuation affects the transmission of mmWave signals passing through the atmosphere [18]. There is a need to note that UAVs may be required to transfer a variety of data, including data, voice and video files, and this presents a unique challenge in terms of low bandwidth and high data transfer rates. Due to this anticipated growth in addition to the crowding of the spectrum, new allocations of frequency are in demand. The mmWave radio frequency band (30-300 GHz) appears to be a suitable candidate because of its vast unlicensed spectrum resources [19]. This is the key in preparing for 5G wireless networks' high requirements [6].

Since Friis's transmission law states that the omni-directional path loss in free space grows with the square of carrier frequency, this poses a problem for the provision of wireless mobile access within UAV-assisted cellular networks. A small UAV can accommodate several antennas because of the short wavelength of mmWave signals [7]. Using the beamforming technique, narrow directional beams can be constructed, and the high path loss and additional losses caused by atmospheric absorption and scattering can be overcome. UAV-assisted mmWave cellular networks differ from conventional mmWave networks with a fixed base station in which the UAV-based system is mobile. The UAV's movement exacerbates some existing challenges. For a mmWave UAV MIMO communication system, [8] proposes an efficient channel tracking method.

2.1.2 UAV NOMA Transmission

Messages from different services can be superimposed with NOMA clusters. The receiver detects and decodes the desired communications signal, when a downlink user has synced with an uplink base station, by canceling the interference signal. A NOMA can be either power-based, code-based, or multiplexed. In the downlink NOMA, the joined signal is transferred from the base stations to the transmitter section. The uplink is a transmission channel through which all users send a signal with a certain amount of transmission power [19]. Utilizing SIC at the transmitter and superposition coding at the receiver, NOMA is generally considered as a primary technology for 5G communications [9]. By taking power domain into account for multiple access, NOMA is able to serve multiple users with a diversified traffic pattern in a non-orthogonal fashion, as opposed to orthogonal multiple access schemes. UAVs can be utilized to satisfy the requirements of different power levels of massive ground users in this way. NOMA is primarily based on the fact that users have different conditions in terms of channel availability. Many studies have already been published on NOMA transmissions for UAV-assisted communications, where UAV-based systems can provide service to multiple users at the same time with same frequency, in particular on the emergency applications that have more users. Fig. 3 illustrates a NOMA transmission with UAV-based network.

2.1.3 Cognitive UAV Networks

The shortage of radio spectrum is the major challenge faced by UAV-enabled wireless networks today. There are several concerning factors to be considered: i) Mobile devices (smart phones and tablets) are increasingly popular on the ground; ii) UAVs operate in different spectrum bands from Bluetooth, WiFi, to cellular networks like LTE [1]. Therefore, UAV communications will face spectrum scarcity due to intense competition for spectrum [10-11]. In order to get further spectrum access, it is necessary to use existing frequencies in a dynamic way for UAV communications. There have been numerous research and standardization groups that have proposed the integration of CR and UAV communication systems to reduce spectrum constraints, known as so-called cognitive UAV communications [12-13]. UAVs operate on the same frequency band as mobile devices on the ground. This concept would allow their coexistence. Because in UAV the links are very strong with its ground users, UAV-to-ground communications may seriously interfere with the existing terrestrial devices.

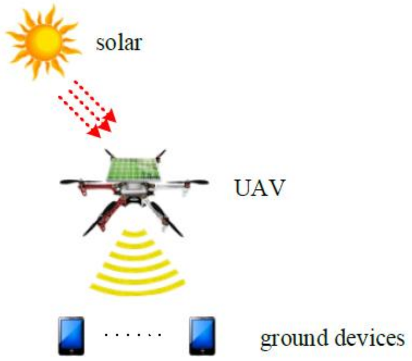

Figure 4. Solar Powered UAV Communications System

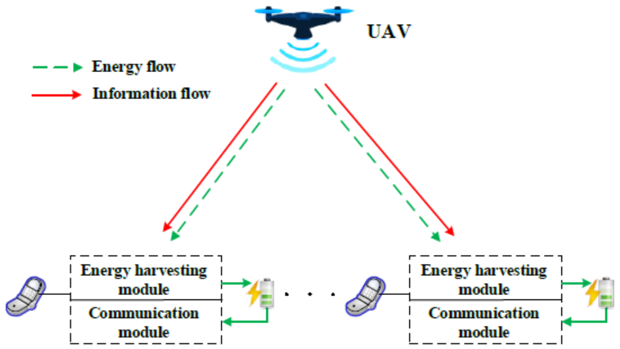

Figure 5. UAV Enabled WPN

2.1.4 Energy Harvesting UAV Networks

UAVs are powered by capacity-limited batteries, in contrast to ground transceivers connected to external power sources. As a result, the UAV-based communications are limited in their ability to perform various tasks involving flight control, sensing and transferring data, or running applications. Typical UAVs can only operate for a limited period of time since they have limited onboard storage [14]. UAV batteries do not need to be charged frequently in the depot, which is not always possible. As a result, the need for stability and sustainability of communications and the performance bottlenecks it creates are crucial.

2.2 Network Layer Methods

In the next generation of networks, multiple nodes will be intelligently and seamlessly integrated in a multi-tier hierarchy, including drone-cell tiers for large areas of coverage, ground small cell tiers for small areas of coverage, D2D communications with user devices, etc. This integration will create new issues for investigating techniques of the network layer. Thus, coordinating the QoS at nodes is necessary.

2.2.1 HetNets with UAV Assistance

An important role for hetnets in supporting 5G/6G is meeting its demands. To meet the growing data demands of mobile services, HetNets plans to efficiently utilize the spectrum [19]. 5G is expected to bring high-speed broadband wireless communications to densely populated areas, and network operators are expected to support streaming multimedia and video downloads as well as diverse services with high wireless data demands. Operators are facing an unjustified burden in terms of capital expenditures and operating costs due to the unrelenting increase in mobile traffic volumes. The deployment of small cells is an intuitive solution to offload cellular traffic. It can be challenging to deploy terrestrial infrastructures for unexpected, volatile, and heterogeneous situations due to mobile environments that are highly sophisticated, volatile, and unreliable. In areas with unpredictable demand, drone-cells [15] could be beneficial in supporting ground cellular networks. For improving the QoS of ground users, short range LoS connections from the air will take the ground users closer to the drone-cells. While drone-cells are mobile, they are also able to serve users with high mobility and high data rate demands. Research can be classified into two avenues of research, one of which involves ground HetNets and the other involves aerial HetNets.

2.2.2 D2D communications combined with UAVs

Network architectures based on D2D communications are becoming increasingly popular. In D2D mode, two neighboring nodes communicate with each other to offload their mobile traffic from BSs, which dramatically increases network capacity. Typically, D2D communications use existing licensed spectrum resources to underlie their transmissions [16]. Fig. 6 shows how the use of UAVs can be a potentially good candidate for constructing a D2D enabled wireless network immediately. In addition, the use of UAVs in conjunction with D2D communications over a shared spectrum band will present important challenges in managing interference. It is therefore crucial to examine what effect UAV mobility has on D2D and network performance.

2.2.3 Software Defined UAV Networks

In recent proposals for next generation wireless networks, the goal is to create a flexible network that is resilient and agile. With SDN, the network is programmable with logically independent control planes and data planes, allowing network reconfiguration to be more effective [17]. Wireless network infrastructure and resources can be managed more efficiently this way. By using a common controller, SDN enables better management than traditional networking due to its greater controllability and visibility. UAVs can be used to collect context information on a distributed basis based on SDN architecture, while ground based systems can be used as controllers to collect data and make network related decisions.

3. Network and Communication Technologies for UAV

Communication modules and protocols are of paramount importance in establishing a successful UAV communication network.

3.1 Communication Modules

The advancement of communication technology has attracted a substantial amount of research work. The different aspects of communications technology has been reviewed in this section and innovative methods for improving them have been proposed. The quality of communication must be accurate and stable to be effective. WiMAX, LTE, and ZigBee, among other wireless technologies, have been discussed in [20]. The data was reconstructed accurately at the receiver end using MIMO-OFDM with minimized computational complexity [21]. A further way of improving the communication system would be to maximize the sum rate.

3.2 UAV Networking Technologies

Many research projects have been devoted to developing better technologies and more robust communication networks for drones, which have resulted in more research being conducted. A study to investigate the feasibility of using Wireless Access Networks, including ZigBee, XBee, WiFi, and WiMAX, based on SHERPA standards is explained in [22]. When properly modified, the AFAR for drones is well suited for the study of flooding, which is recommended for drones [23]. AFAR-D has proven to have a better packet delivery ratio with the DSDV routing protocol. Specifically, RMICN was developed to facilitate communication between disjointed networks. To increase flexibility and efficiency, the device used moving physical controls to control satellites and relay nodes. Path planning for mobile robots was accomplished using an algorithm named IACO [24].

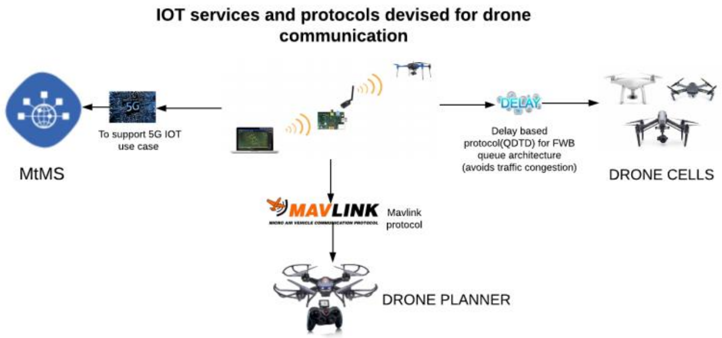

Figure 6. An example for drone communication using the internet

3.3 IoT-Enabled UAV Communication System

A recent development in the interconnectivity of devices is the IoT [25]. In recent years, the internet is used more and more in more aspects of our daily lives [42]. For IoT systems to be environmentally sustainable, they must be energy-efficient and require efficient data management systems [25]. With the IoT technology, people and things are practically connected, and wireless sensor networks and nodes are utilized to create information systems [43]. Drones cannot run applications requiring high computation power and storage because of their limited processing capabilities. This shortcoming can be solved by integrating drones with the internet of things and the cloud. In [26], MTMS was proposed as a machine type multicast service to enable concurrent data transmission. Designed to minimize energy consumption and control overhead, its architecture and procedures are optimized for latency and energy efficiency. Several papers have explored the use of the IoT in end-to-end systems and reached significant conclusions. As shown in Fig. 6, a fully functional drone system with IoTs supports its communication is typically designed with several different components.

3.4 UAV-Enabled Mobile Edge Computing

UAV communication has been facilitated by MEC, which provides communication and processing services to users [27-29]. An increase in computing efficiency and reduced execution latency is expected from UAV-enabled MEC networks. The current MEC network, with fixed base stations and minimal computing capacity, is proposed to be enhanced with UAV-enabled edge computing nodes to address the shortcomings. Moreover, UAVs can extend their operational time through WPT and energy harvesting. In addition, they optimized the number of computing bits used to load data, the frequency of local computations between users, and the trajectory of the UAV. Though, the UAV's battery life and runtime are very limited, it has to communicate with lot of users in the coverage area. In case of UAV enabled MEC networks with multiple users and different UAVs, it is still necessary to establish an efficient resource allocation scheme.

3.5 URLLC-Enabled UAV Communication System

Modern wireless networking technologies, such as autonomous vehicles, will be enabled by URLLC, which will greatly enhance the performance of 5G networks [30-33]. A new challenge for UAV communication arises from the control signal transmission between the UAV and drone operator. Providing real-time collision monitoring is critical to the safety of such high-speed connections. Latency and reliability requirements are important.

4. UAV Types and Energy Consumption Models

The wide range of applications of UAVs allow them to come in many forms. The different categories of UAVs can be classified based on parameters such as weight, size, wing configuration, flight altitude, and power supply. Weight is typically the criterion used by civil authorities to classify drones. Here, the use of small UAVs for wireless network communication, and how they may be deployed flexibly are emphasized. There are two major types of UAVs used in practice based on their wing configurations: fixed-wing and rotary-wing. Generally speaking, fixed-wing UAVs tend to have faster speeds and consume less power than their rotary-wing counterparts of the same size. These fixed-wing UAVs can hover in fixed locations, however require runways in order to land and take off. Both types of UAVs consume different amounts of energy.

4.1 Modeling the energy consumption of fixed-wing UAVs

UAVs have a difficult time obtaining a reliable theoretical model of their energy consumption, which is influenced by many factors including weight, wing area, air density, velocity, and acceleration. In [34], simplified fixed-wing energy consumption models with level flight were calculated without considering the abrupt deceleration and consequent reverse thrust from the engine.

4.2 Energy consumption of rotary-wing UAVs

As the flying mechanism of UAVs with rotary-wings is totally different from those with fixed-wings, this model cannot be used to estimate their energy consumption. The energy consumption model for arbitrary 3D flight of a rotary-wing UAV is also nontrivial to construct using closed-form expressions. In [35], a theoretical model of rotary-wing UAV energy consumption that ignores the effects of acceleration and deceleration on UAV energy consumption was derived.

4.3 Green UAV Communications

6G networks face a serious challenge in greening their UAV communications. Despite having a limited amount of onboard energy, UAVs have a very limited lifespan. In contrast, UAVs require high energy consumption as they are required to propel and communicate at the same time. As a result, the green UAV communication has received extensive research. There are basically three types of green UAV communications available today: (i) Intended to save energy with UAV-assisted networks (energy-saving UAV communications); (ii) For

UAVs, the use of energy harvesting provides wireless energy supply for the system; (iii) Reconfigurable intelligent surfaces for UAV communications aim to save energy by passively reflecting low power.

4.4 Methods for achieving green UAV communications

UAV-enabled wireless networks can be made more energy efficient by employing a wide range of techniques. Utilizing the characteristics of UAVs can lead to greater gains than conventional terrestrial networks. Reducing path losses is one way to increase energy efficiency. By flying close to the target user, the UAV can reduce the distance from the user to the UAV. Moreover, the ground channel of the LoS air is also useful for reducing path loss. Green UAV communications also require power allocation, wide bandwidth, and energy harvesting, in addition to reducing path loss.

4.4.1 Exploiting the mobility

The high mobility of UAV-ground networks is one of their biggest advantages over terrestrial wireless networks. One advantage of the UAV is that it can function as a wireless link on demand, particularly during emergencies. However, the mobility nature of UAV can provide an opportunity to reduce the link distance, thus improving energy efficiency. The mobility of UAV can be exploited in wireless networks through two general methods. Static UAV placement involves the deployment of the drones in fixed locations for ground users to utilize. UAVs' mobility is another factor that can be used for further reducing link distance, making them a viable option.

4.4.2 Power allocation

The allocation of power is a classic method for improving the energy efficiency and performance of a network. The UAV's position influences the distance between air and ground nodes most of the time since the ground nodes are installed at fixed location. One common method of providing more power to UAVs that are close to their targets, while decreasing the path loss, is to give the UAV more power as it approaches the target. As soon as the UAV flies near a multiuser system that relies on UAVs, the transmit power may be allocated to that user. Power allocation is therefore a significant way of increasing gains.

4.4.3 Directional transmission

Focusing the emitted energy in the desired direction is an important method for saving the energy in wireless networks. By using directional antennas, a higher level of gain can be attained through terrestrial channels. This can be attributed to the high likelihood of LoS air-ground channels. In terrestrial base stations, the entire antenna is typically angled down to serve the ground users, whereas only the sidelobe is capable of serving the flying UAVs. UAVs that are connected to cellular networks need to take into consideration the antenna gains for their base stations to ensure energy efficiency.

5. Applications of UAV

According to their history in mobile networks, 6G networks inherit the benefits of 5G [39]. 6G will enhance certain 5G methods and introduce some new capabilities. The 6G network will therefore rely on a variety of technologies [39]. Research on 6G is still at an early stage, as well as are the requirements for 6G. Because UAVs are reasonably cheap and can be deployed with ease, UAV communications are expected to play a large role in the future 6G network [36-37]. UAV communications are suitable for improving the flexible coverage of the 6G network since the network is supposed to be ubiquitous. It is expected that the 6G network will provide full coverage, full applications, full spectral content, and strong security. A variety of UAV communication techniques are therefore promising candidates for 6G. A 6G network, for example, is aimed at providing ubiquitous connectivity. UAVs can be utilized as aerial base stations in cases where there is no ground station for enabling source communication or when the ground station has been damaged. UAV communications are suitable for a wide range of applications due to their reduced cost and flexibility.

5.1 Aerial base stations for UAV

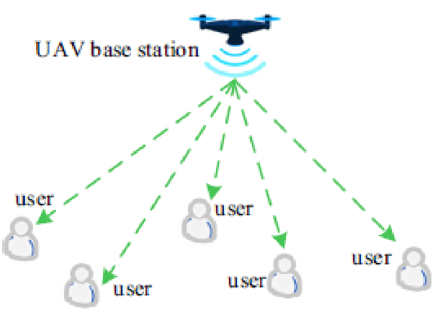

Figure 7. UAV aerial base station

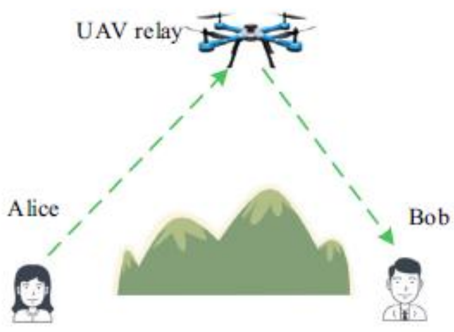

Figure 8. Relaying UAVs

As aerial base stations, UAVs can provide coverage to many ground users with their wireless signals. As a result, fast response is capable of connecting the ground users even when the terrestrial base station is damaged. Due to the finite amount of energy on board UAVs, energy-saving approaches are necessary to extend their lifespan. UAV with rotary wing can serve ground users at fixed locations when serving quasi-static aerial base stations.

5.2 Relaying UAVs

An UAV can be deployed easily to give network access in outdoor applications without terrestrial communication infrastructure. By using macro base stations, UAVs are used to connect the isolated devices. Military and disaster rescue operation are among the many situations in which UAVs are beneficial. UAV-enabled relaying systems are gaining huge attention due to their flexibility and low cost. Initial research about UAV relaying is primarily concerned with transmission rate, throughput, and reliability, without adequately considering UAV's energy consumption.

5.3 Data gathering with UAVs

Wireless sensor networks are capable of sensing harsh environments with no terrestrial communication infrastructure. However, collecting data can be hazardous or expensive in these environments. It is a promising solution to gather data using UAVs in this case. Sensor nodes and UAVs need to be energy-efficient, as they are usually not supplied with fixed power. The constant speed and trajectory of UAVs allow them to fly circularly in order to save energy. Energy-efficiency analyzed with trajectory radius adjustment and routing in the WSN with fixed-wing UAVs are discussed in [38].

5.4 UAV-Enabled Mobile Edge Computing

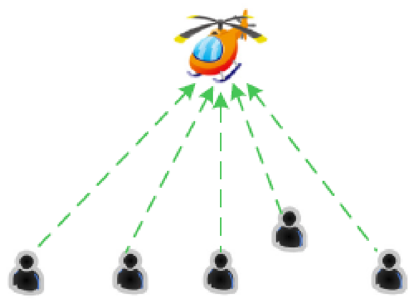

Figure 9. Data gathering with UAVs

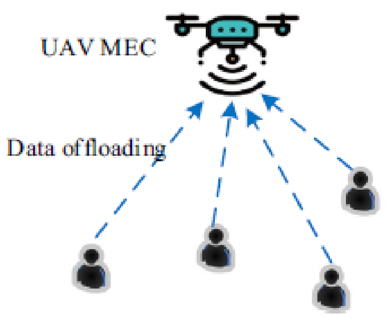

Figure 10. UAV-Enabled Mobile Edge Computing

A mobile edge computing solution can be used by remote nodes that are far from the cloud and have limited computing capacity. In addition to delivering computing power to isolated nodes, UAVs can also carry processing power. The processing of the edge computer's CPU also consumes energy in mobile edge computing systems powered by UAVs. CPU energy consumption increases cubically with CPU frequency, which means that higher CPU frequency reduces computation latency by requiring more energy to finish the computation. As a result, latency and energy consumption are traded off.

6. Challenges of UAV

Safety **-** Global Positioning Systems (GPS) are used for navigation by commercial UAVs, just like recreational drones. With this information, controllers can accurately determine the location of a vehicle, even if it is at a considerable distance. A common problem with GPS, however, is that it fails to notify controllers of the surrounding area. As UAVs lack the capability to recognize other objects in the air, they can interfere with the flight pattern of other aircraft and entail potential safety risks. Geofencing addresses this issue by allowing drones to cling to a virtual fence. By creating these no-fly zones, manned aircraft are protected from unmanned systems in restricted areas or at high altitudes where they could interfere with aircraft operations.

Privacy- An abundance of data can be collected by UAVs, which are the "eyes in the sky". Other information that can be collected by the systems, in addition to video surveillance, includes detection of sounds, magnetic fields, and chemical composition. This process of collecting data may be seen by the public as intrusive, as if they are being monitored. Federal legislation has been introduced to address these privacy concerns.

Security **-** Other sources may attempt to jam or hack the signals of UAVs as they collect and share data. It can create further anxiety and frustration among members of the public when sensitive data might end up in the wrong hands. In unmanned aerial systems, RF shielding can improve the security of this data. The vehicle's enclosure reduces transmissions that make its signal more susceptible to interference from other sources.

Power **-** UAVs have a greater economic impact when they can stay in the air longer. In mapping applications, they can cover large areas and efficiently perform surveillance of infrastructure. For example, they can deliver packages and medicine to further away locations. The weight of UAVs is also an important consideration, in addition to the advances in battery and engine technologies for longer flight times. It is possible for product to fly for longer periods by designing lightweight components. As a result, technology can be applied to more applications.

7. Conclusion

Recent years have seen a rise in interest in the use of UAVs for communication. Due to their low cost, flexible deployment, and high possibility of LoS channels, the UAV communications have been viewed as a reliable technique for future 6G communications. UAVs can be used as aerial communication nodes in emergencies like military operations and natural disasters, establishing wireless links quickly. The energy shortage on UAVs, severely limits their potential use in the future. UAV communications using 6G must therefore be developed, and hence this paper reviews recent developments in 6G UAV communications. Moreover, it discusses the different types of UAVs, and their energy consumption models. Metrics are also presented, and typical green UAV communication methods are described. In addition, common applications for UAV communications have been discussed. This paper describes a review of recent research activities focusing on UAV communications with 5G technologies from the physical and network layer perspectives.

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