Green Air-Ground Integrated Heterogeneous Network in 6G Era

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Abstract: The research of three-dimensional integrated communication technology plays a key role in achieving the ubiquitous connectivity, ultra-high data rates, and emergency communications in the sixth generation (6G) networks. Aerial networking provides a promising solution to flexible, scalable, low-cost and reliable coverage for wireless devices. The integration of aerial network and terrestrial network has been an inevitable paradigm in the 6G era. However, energy-efficient communications and networking among aerial network and terrestrial network face great challenges. This paper is dedicated to discussing green communications of the air-ground integrated heterogeneous network (AGIHN). We first provide a brief introduction to the characteristics of AGIHN in 6G networks. Further, we analyze the challenges of green AGIHN from the aspects of green terrestrial networks and green aerial networks. Finally, several solutions to and key technologies of the green AGIHN are discussed.

Keywords: air-ground integrated heterogeneous network; 6G; green communications

DOI: 10.12142/ZTECOM.202101006

https://kns.cnki.net/kcms/detail/34.1294.TN.20210309.0907.004.html, published online March 09, 2021

Manuscript received: 2021-01-29

Citation (IEEE Format): H. C. Wu, H. J. Li, and X. F. Tao, "Green air-ground integrated heterogeneous network in 6G era," *ZTE Communications*, vol. 19, no. 1, pp. 39 - 47, Mar. 2021. doi: 10.12142/ZTECOM.202101006.

1 Introduction

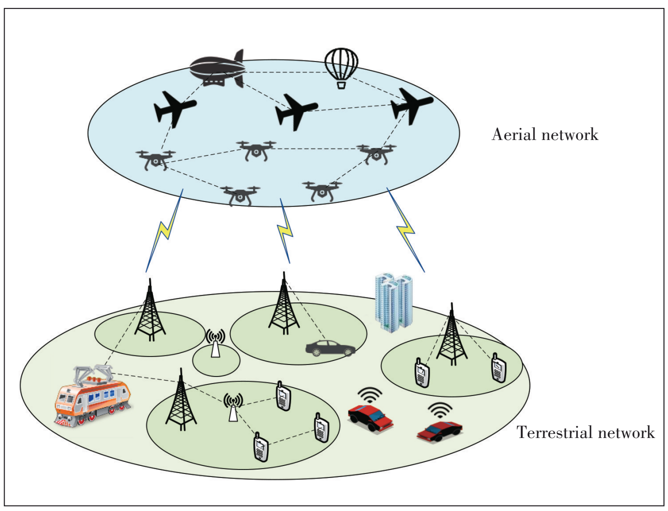
The improvement of network capacity, coverage, delay, security, etc. has always been a key and core task in the development of ground mobile communication networks. Three-dimensional integrated communication is one of the key research directions in achieving the ubiquitous connectivity, ultra-high data rates, and emergency communications in the six generation (6G) networks[1]. Aerial and space networks facilitate adaptive, flexible, scalable, efficient, and reliable three-dimensional wireless coverage for wireless terminals, which have attracted much attention from industry and academia societies. The air-ground integrated heterogeneous network (AGIHN) integrating various aerial communication platforms and terrestrial infrastructures is a cost-efficient paradigm to facilitate extended wireless coverage, ultra-high data rates, post-disaster communication assistance and recovery etc.

A typical AGIHN architecture is shown in **Fig. 1**, where aerial communication platforms such as airships, balloons, and unmanned aerial vehicles (UAVs) acting as the carrier of information collection, transmission and processing can provide broadband wireless communications and supplement terrestrial networks. Terrestrial networks mainly consisting of

This work was supported by National Natural Science Foundation of China under Grant Nos. 61901051 and 61932005.

heterogeneous cellular networks, wireless local area networks (WLAN), and mobile ad hoc networks (MANET) support various applications and services in the areas where infrastructures are easy and low-cost to be deployed.

Nowadays, industry and academia societies have started research and implementation of AGIHN. For example, in 2016, Nokia Bell Labs demonstrated the world's first flying cell (F-Cell) based on UAV, which was powered by solar energy and could wirelessly transmit high-definition video[2]. In 2017, EE, the British Telecom Operator, broadcast the mountain bike race live on the mini mobile site "Air Mast" connected to the helium balloon[3]. As of December 2019, the FirstNet communications platform jointly built by AT&T and First Responder Network Authority had reached more than 1 million connections[4]. Flying Cells on Wings (COWs) in the platform is an ideal choice for wildfire and mountain rescue missions. During Hurricane Michael, a COW provided services to first responders on the battered Mexican beach in Florida to support disaster recovery. One Aerostat, which was launched later, can provide more than twice the coverage area compared with COWs, helping responders keep connected in the event of a large-scale catastrophic event.



▲ Figure 1. Architecture of air-ground integrated heterogeneous network (AGIHN)

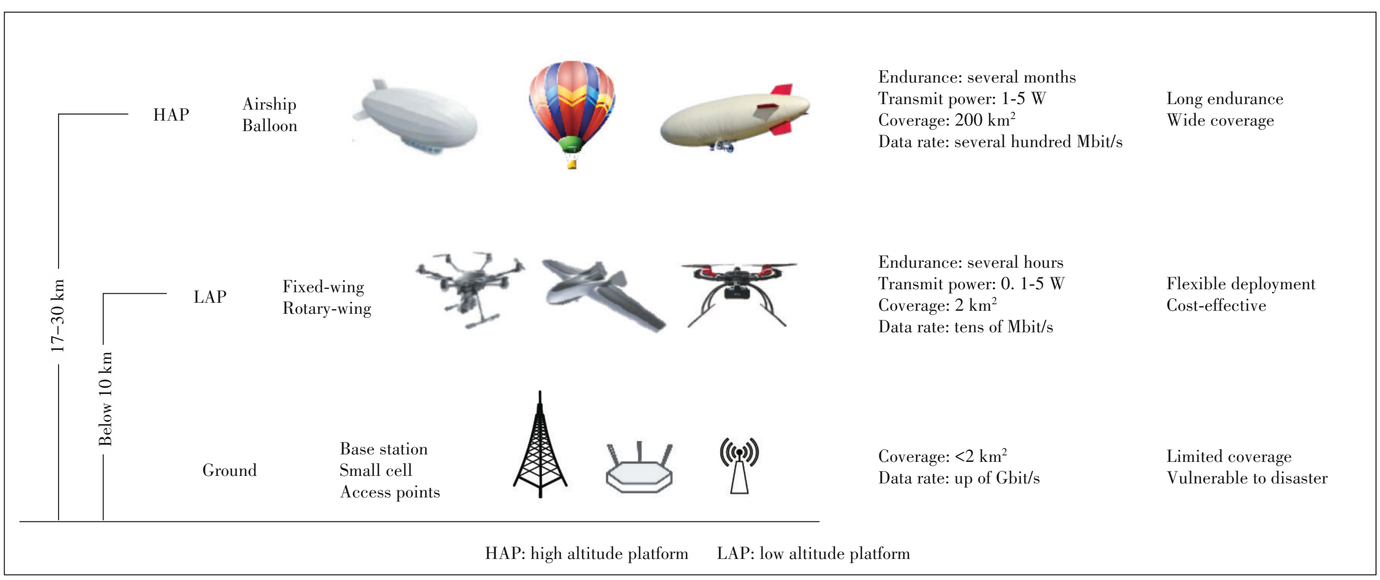
1.1 Characteristics of AGIHN

1.1.1 Heterogeneity

In addition to terrestrial heterogeneous cellular networks, high altitude platforms (HAPs) such as airship and balloon and low altitude platforms (LAPs) such as UAVs are employed in the aerial networks to achieve seamless wireless coverage and to meet differentiated data rate requirements. This heterogeneous integrated network enables diverse systems to cooperate, coordinate, and share information for serving mobile terminals with individuation service anytime and anywhere.

As shown in **Fig. 2**, AGIHN is a large-scale and multi-layer 3D heterogeneous network. HAPs such as airships and balloons are distributed in remote rural areas with imperfect terrestrial infrastructure or disaster areas, with an altitude of 17 – 30 km[5]. UAVs are used for high-speed services in hot spots or wireless connection in disaster areas, with an altitude below 10 km[6]. Terrestrial base stations (BSs) and access points (APs) are typically deployed in the area with an altitude below 1 km.

Terrestrial heterogeneous cellular networks realize coverage optimization and capacity improvement by deploying dense small cells with lower transmission power, such as microcell, picocell and femtocell. Due to economic cost and terrain constraints, these terrestrial communication infrastructures are established according to the human habitation and living habits,



▲Figure 2. Heterogeneity of air-ground integrated heterogeneous network (AGIHN) which makes wireless traffic a stable and periodical spatial-temporal distribution.

Aerial networks, as a supplement to terrestrial networks, have to deal with the complex and diverse application scenarios with uneven spatial-temporal distributed traffic, diverse service demand, and sudden surge of wireless traffic. Flexible movement is a key feature of AGIHN. HAPs are quasi-static (relative to the ground) platforms. The moving speed of UAVs is 0 – 460 km/h[7]. Moreover, UAVs can move freely in the 3D space with random trajectory. The ground BSs are typically fixed and deployed in buildings or on high mountains. Ground terminals such as vehicles and terminals on high-speed rails typically have speeds of 0 – 350 km/h and move with relatively fixed trajectories[8]. Power supply of network nodes in AGIHN is also diverse from each other. There is no continuous power supply source for aerial nodes. Battery, wind, solar, and other combined power supply are the main energy sources for balloons. The endurance of such platforms can reach 150 – 200 days[9]. UAVs generally use battery power supply and the endurance is only about half an hour to 24 hours[10]. Ground BSs and APs are driven by grid power system for continuous operation.

For the frequency bands and radio propagations of ground 4G and 5G networks, the frequency resources occupied by 4G system include 1 880 – 1 900 MHz, 2 320 – 2 370 MHz and 2 575 – 2 635 MHz, while the frequency resources occupied by 5G system include 3.3 – 4.2 GHz, 4.4 – 5.0 GHz, the millimeter wave band, 26 GHz, 28 GHz and 39 GHz[5]. The aerial nodes such as UAVs, balloons and airships work at the Long Term Evolution (LTE) or Wi-Fi communication bands[11]. They can also work in the unlicensed Industrial, Scientific and Medical (ISM) band defined by the ITU Radiocommunication Sector (ITU-R)[12]. The electromagnetic propagation of different frequency bands also differs from each other. Radio attenuation on high frequency bands is more serious. Compared with the electromagnetic fading at 2 GHz, an additional 22.9 dB of fading exists at 28 GHz[13]. Good line-of-sight (LoS) transmission links exist in air-to-air, air-to-ground, and ground-to-air channels while the radio propagation in ground transmissions faces more serious signal fading due to rich reflection, refraction, scattering, etc.

1.1.2 High-Dynamically Changed Network Topology

Flexibility is one of the most key features of aerial networks. Payload, height, speed and endurance are the four key factors influencing communication performance of aerial platforms. Payload represents the maximum carrying weight that the platform can hold. HAPs and LAPs carry different communication equipment with different weight. Height refers to the maximum altitude that the aerial platform can be reached, which is closely related to the coverage of the aerial platform. Endurance refers to the maximum flight duration without charging and refueling. As mentioned above, the height, speed and endurance of difference components in AGIHN differ from each other, which results in the high-dynamic change of the network topology.

Different height and moving speed of diverse platforms make the network topology more stereoscopic. In order to provide flexible services for wireless terminals, communication platforms change their positions and height adaptively. As a result, the network topology changes dramatically with the moving of platforms. The endurance is another key factor having great impact on the network topology. The network topology of ground networks changes slightly since ground BSs and APs are generally fixed located and are powered by grid system while that of aerial networks changes frequently and rapidly due to the energy depletion and battery charging. Besides, AGIHN are more vulnerable to malicious attacks such as wiretapping, hijacking, masking, and jamming, which cause disconnection and interruption of aerial links and re-connection of surviving nodes. The disconnection and re-connection of networks nodes in AGIHN also contribute to the changes of network topology.

1.1.3 Random Perturbation of Aerial Platforms

Due to the lack of fixed infrastructure, the aircrafts are susceptible to airflow and body vibration, leading to random perturbation of aerial communication platforms. According to the tests and measurements, the variation of roll angle (i.e., the elevation angle in this paper) is ±0.02 rad. The variation of pitch angle (i. e., the azimuth angle in this paper) is ±0.1 rad[14]. The random perturbations of aerial platforms may cause error to the estimation of angle of departure (AOD) and angle of arrival (AOA) between transceivers, further leading to the error of channel state information estimation and distortion of coverage area. Consequently, the perturbation of aerial platforms will cause non-robust transmission links, inefficient energy consumption, and serious information leakage, etc.

The perturbation angle of UAV was assumed as high as 10 degrees in Ref. [14]. It shows that the jitter of UAV causes inaccurate estimation of deviation angle between the UAV and ground users and increases the error of AOD estimation. The influence of wind on UAVs was then simulated by using onboard sensors in Ref. [15]. The maximum amplitude of sideslip angle and trajectory angle jitter was approximately 10 degrees, which verifies the previous hypothesis. Considering the impact of UAV jitter, energy-saving secure communications in a downlink A2G wiretap system was investigated in Ref. [16].

1.2 Integrating AGIHN in 6G

With the commercialization of 5G networks, various groups from worldwide countries and regions have initialized plans and programs on potential key technologies for 6G networks. Space-air-ground integrated networking (SAGIN) is acknowledged as a key direction in achieving global connectivity. AGIHN, as an important part of SAGIN, is seen as a cost-effective approach to meeting the requirement of ultra-high data rate and ubiquitous coverage. To realize the expected goal, the integration of ground networks and aerial networks has to solve the problem of new network architecture design and the challenge of disruptive technology innovation.

1.2.1 Directions of Network Architecture Design

Network architecture design is the first step to realize the integration of ground networks and aerial networks. Efficient coordination of resources and fully exploitation of cooperation between ground networks and aerial networks are the main goals in network architecture design. In order to solve the complex interoperation in the management of heterogeneous networks, the software defined network (SDN) and network function virtualization (NFV) are applied in 5G networks. SDN and NFV are still seen as efficient solution to the network management in 6G networks. In the AGIHN with high-dynamically changed topology, SDN and NFV based core network management architecture can provide distributed and on-demand resource allocation, service guaranteed network slicing, flexible programming of network functions, and security management[17–20]. SDN and NFV are also seen as promising technologies for providing flexible and reconfigurable green satellite services in space-air-ground integrated networks[21].

Efficient energy utilization and low energy consumption are always key concepts in network architecture design. Green AGIHN architecture design can be carried out from the aspects of green communications and green computing. For green communications in AGIHN, the aerial platforms can provide cost-effective and energy-saving transmissions for the wireless terminals with appropriate cooperation, trajectory design, user scheduling, power allocation, and combination with improved wireless technologies[22–25]. Coordination and cooperation architecture of AGIHN and resource management of heterogeneous network nodes are the keys to green communications of AGIHN. For the green computing, aerial communication platforms with mobile edge computing (MEC) can greatly improve the data rate and latency performance in AGIHN[26]. Moreover, distributed cloud architecture can achieve seamless handover and effective task offloading among UAVs and ground terminals[27]. Green computing in AGIHN can be realized with energy-efficient MEC and green cloud architecture.

Intelligence is a core idea in the 6G era. To realize ubiquitous intelligent mobile society in the 6G era, artificial intelligence (AI) is expected to fully penetrate the network evolution. With AI applied in AGIHN architecture design, efficient resource management and network optimization can be realized by exploiting the potential information in wireless big data and with less or even no human intervention. Moreover, enhanced privacy preserving can be achieved by leveraging AI in aerial networks[28].

1.2.2 Directions of Key Wireless Technologies

1) Terahertz communications

AGIHN is facing the contradiction between limited spectrum resources and the rapid growth of high-speed traffic demand. Terahertz communications is an important direction to break through the resource limitations in 6G networks[29]. The terahertz frequency resources is from 0.1 THz to 10 THz. Terahertz communications has the advantages of ultra-low delay, excellent directivity, anti-interference, wide bandwidth, and strong penetration. Moreover, since the terahertz wavelength is greatly reduced, the antenna size can be greatly reduced, which is beneficial to antenna integration. Leveraging terahertz technology to aerial networks can further improve the data rate with highly concentrated beams, strong LoS path and wide bandwidth resources. However, the short terahertz wave and the weak diffraction introduce quite high path loss of radio propagation. Thus, denser BSs and APs are required to achieve seamless coverage, which means more energy consumption will be introduced.

2) Intelligent reflecting surface

Reconfigurable intelligent reflecting surface (IRS) is attracting attention for wireless networks since it can significantly improve the wireless channel quality by adaptively reconfiguring wireless propagations with massive low-cost passive reflecting elements integrated into a planar surface[30]. Combining IRS with non-orthogonal multiple access (NOMA) and MEC can greatly improve network throughput and reduce latency[31–32]. Leveraging IRS in AGIHN, the received signals at the UAV from cellular BSs can be greatly improved by configuring IRS deployed on building walls. The secrecy rate can be enhanced by jointly optimizing phase shifters of IRS, UAV trajectory, and UAV power[33]. Moreover, leveraging UAVs with IRS can provide energy-efficient communications, which provides new sights in green communications in 6G networks[34].

3) Spectrum sharing

Spectrum resources are the treasure for wireless communications. In addition to terahertz communications and visible light communications, spectrum sharing is another approach in extending spectrum resources and improving spectrum efficiency in 6G networks with flexible and intelligent frequency allocation and reuse[35]. Employing blockchain in spectrum sharing can further prevent jamming from malicious users[36]. Spectrum reuse between dense ground BSs and flexible-mobility UAVs makes interference management more challenging. With appropriate spectrum sharing between aerial networks and ground networks, the area spectrum efficiency and network throughput can be significantly improved.

4) Energy harvesting technologies

With the proliferation of mobile devices and the denser deployment of network BSs and APs, prolonged battery life and improved energy harvesting efficiency are the keys to realize green AGIHN. Simultaneous wireless information and power transfer (SWIPT) is one of the popular energy harvesting technologies studied in recent years[37]. SWIPT can charge wireless devices while supporting communications and is a promising energy charging technology for sensors nodes. Leveraging SWIPT in AGIHN, the aerial platforms can effectively charge ground terminals and improve energy efficiency by exploiting the benefit of flexible mobility. In addition, SWIPT combined with IRS in aircrafts can further improve the energy harvesting efficiency[38].

2 Challenges of Green AGIHN

According to the forecasts of International Energy Agency (IEA) and Global Electronic Sustainability Initiative (GESI), the information and communication technology (ICT) industry currently consumes 2% – 4% of the global energy, which is equivalent to the amount of energy consumption of the aviation industry[39]. The huge energy consumption not only increases operating costs, but also brings series of resource and environment problems. It is requested by the ITU that the global ICT industry reduce greenhouse gas (GHG) emissions by 45% from 2020 to 2030[40]. How to improve energy efficiency of the communication industry is an urgent problem to be solved in the 6G era.

In AGIHN, aircrafts acting as information carriers can reduce more energy consumption and provide better energy-efficient services compared with terrestrial networks due to the reduced energy consumption of ancillary facilities such as the air conditioner at BSs. Nevertheless, the green communication in AGIHN still faces many challenges.

2.1 Challenges of Green Terrestrial Networking in AGIHN

2.1.1 Optimized Deployment of BS and AP

In AGIHN of the 6G era, more ground BSs and APs will be deployed to accomplish the requirement of ultra-high data rate services. More infrastructures will be established to support the deployment and operation of BSs and APs. Accordingly, more energy will be consumed. According to energy efficiency requirements for telecommunications proposed by Verizon[41], BSs consume nearly 80% of the energy consumed in cellular networks while the power amplifiers and air conditioners consume almost 70% of the total energy at BSs[42]. It is reported by Huawei that the maximum energy consumption of a 5G BS is about 11.5 kW, which is 10 times of that of a 4G BS[43]. However, according to Daiwa's prediction, the number of 5G BSs will be four times that of 4G BSs in their respective eras[44]. With the employment of advanced wireless technologies, the deployment of BSs will be much denser in 6G networks. It is foreseen that there will be up to 40 000 sub-networks per km^2 in 6G networks[45]. Optimizing the deployment of BSs and APs is one of the key approaches in reducing the energy consumption in AGIHN.

In addition, the ground wireless traffic is non-uniformly distributed in both time and space. It is predicted that the data traffic in the downtown of Milan is 4 times of that in Boccono University located in suburb[46]. An analysis report of data traffic in Shanghai reveals that the data traffic in residential areas is 1.5 times of that in office areas[47]. Moreover, the ratio of daytime traffic amount to night-time traffic is around 0.8 in residential areas while it is up to 1.4 in office areas. Although aerial networks can provide flexible services for ground terminals in such areas with non-uniform traffic, fixed terrestrial communication infrastructure is still the main approach for providing robust and cost-effective services. To satisfy the requirement of temporal and spatial non-uniform traffic and to simultaneously save energy, flexible BS sleeping and awake schemes play important roles in saving energy at BSs[42].

2.1.2 Increased Mobile Devices and Wireless Access

According to Cisco, there were 8.8 billion mobile devices and wireless connections in 2018, induduing 4.9 billion smart phones and 1.1 billion IoT devices[48]. 42% of the devices enjoyed wireless services through 4G cellular networks. Due to the continuous prosperity of sensors, intelligent furniture, Internet of vehicles, smart city and medical applications, and the continuous penetration of vertical industry with 5G networks, there will be 28.5 billion wireless devices by 2022[49], among which 51% (14.6 billion) of the devices are battery-powered machine-to-machine (M2M) devices. It is estimated that by 2025, the global network standby energy consumption of IoT edge devices will approach 46 TWh[50], which is about equivalent to the annual electricity consumption of Portugal in 2019[51].

The massive wireless connectivity brings a great challenge to the wireless access networks due to massive connection requests, ultra-heavy traffic load, limited battery of wireless devices, and diverse levels of subscribers. Moreover, burst access attempts may happen due to some unexpected events such as power failure, which will lead to a sharp increase of control signaling, network congestion, and further increased energy consumption. In addition, handover of massive devices among heterogeneous networks introduces complex interoperation and resource managements, which also causes the increase of energy consumption. Low energy consumption and improved energy efficiency are crucially important for wireless communications in future networks.

2.2 Challenges of Green Aerial Networking

Although aerial platform-based communications can save more energy than ground communications, the explosive growth of aircrafts in wireless communications and the high-dynamically changed topology bring new challenges to the green communications. The UAV is the most widely applied aircraft for wireless communications due to its flexible mobility, cost-efficient and rapid deployment, and LoS communication support. The Federal Aviation Administration (FAA) pointed out that, by 2024, the world will see the emergence of 1.48 million recreational Unmanned Aircraft System (UAS) fleets[52].

A small UAV usually needs 20 to 200 W/kg to fly[53]. It is usually powered by on-board batteries. Different types of UAVs carry different battery capacities. For example, the Skywalker fixed-wing UAV carries four 8 500 mAh batteries in series, while the AKS Raven X8 multi-rotor UAV carries two 10 000 mAh batteries[54]. The battery power consumption of 30 kg to 35 kg UAVs to complete a flight mission (i.e., lifting up, hover, flight, and landing) is about 12.53% and 13.82% of the full amount[55]. The power consumption of Wi-Fi and GPS communications of a small UAV with the weight of 865 g is about 8.3 W, and that of horizontal flight is 310 W[56]. Therefore, in the case of limited battery, reducing the power consumption of UAV can provide longer endurance and communication services.

2.2.1 Green Communication Module

Limited battery limits the performance of aerial transmissions. Improving the energy efficiency of communication modules of aircrafts and increasing the battery capacity are the two main approaches for green communications of aerial networking. Aircraft placement, trajectory optimization, power control, flight duration optimization, resource and interference management, and handover in high-dynamic networks are the main factors influencing the energy consumption and energy saving in AGIHN.

Radio propagation and load balance among BSs or APs are closely related with the placement and trajectory design of aerial communication platforms. For HAPs, the placement optimization directly influences the load balance between HAPs and ground BSs. Appropriate placement of HAPs can extend wireless coverage, improve network throughput, and further reduce energy consumption of the communication modules. For LAPs, optimized trajectory design can improve network throughput, reduce energy consumption, and extend flight duration. The trajectory design of multi-UAV networking can further provide seamless connectivity for wireless terminals and extend the coverage area of aerial networks. It should be noted that collision avoidance among multiple UAVs should be considered in the trajectory design. Frequency reuse, spectrum sharing, and power control are key factors in resource and interference management between aerial networks and terrestrial cellular networks. Flexible and adaptive frequency reuse and power control can decrease interference among aerial nodes and ground nodes, which can further improve network throughput and improve energy efficiency.

2.2.2 Green Flight Module

A UAV consumes more propulsion power in flight than in hover[56]. LAPs have the advantage of mobility compared with HAPs while they consume more power due to their high-dynamic mobility. The flight power consumption of a fixed-wing UAV can be expressed as functions of its velocity V and acceleration $a(t)$[57]:

$$P\left(V,a(t)\right) = c_1 V^3 + \frac{c_2}{V} + \frac{c_2}{Vg^2} a^2(t), \tag{1}$$

where $c_1 = \rho C_{D_0} S/2$ and $c_2 = 2W^2/\left(\pi e_0 A_R \rho S\right)$ are two parameters (where ρ and C_{D_0} are the air density and zero-lift drag coefficient, respectively, S and W are the wing area and aircraft weight, respectively, and e_0 and A_R denote the wing span efficiency and aspect ratio of the wing, respectively); g is the gravitational acceleration. According to Eq. (1), we can see that the energy consumption increases with the increase of velocity and the absolute value of acceleration, which means that more energy will be consumed with higher flight speed and faster change of the speed. Therefore, in order to achieve green flight of UAV and further to achieve green aerial communications, the UAV should move as smoothly as possible while improving the transmission performance. The flight power consumption of a rotary-wing UAV is a function of the UAV velocity, which is given by Ref. [58]:

$$P(V) = P_0\left(1 + \frac{3V^2}{U_{\text{tip}}^2}\right) + P_i\left(\sqrt{1 + \frac{V^4}{4v_0^4}} - \frac{V^2}{2v_0^2}\right)^{1/2} + \frac{1}{2} d_0 \rho s A V^3, \tag{2}$$

where $P_0 = \delta \rho s A \Omega^3 R/8$ and $P_i = (1+k) W^{3/2}/\sqrt{2\rho A}$ are two parameters representing the blade profile power and induced power of the UAV in hover, respectively (where δ is the profile drag coefficient, s and A are the rotor stiffness and rotor disc area, respectively, Ω and R denote the blade angular velocity and rotor radius, respectively, and k denotes the incremental correction factor to induced power); U_{tip} is the rotor tip velocity; v_0 is the average rotor induced velocity in hover; d_0 denotes the fuselage drag ratio. According to Eq.(2), the first and the third terms are the power required to overcome the profile drag of the blades and the fuselage drag, respectively, which increases with the square and cubic of the velocity. The second term is the power required to overcome the induced drag of the blades, which decreases with the velocity. It is verified in Ref. [58] that the total power consumption first decreases and then increases with the increase of UAV velocity, which means that the energy consumption can be minimized with the optimal UAV velocity.

As a result, the improvement of transmission quality and energy efficiency in AGIHN should take flight consumption into consideration. There are three main research directions for energy-saving UAV communications: the optimization of flight radius and velocity with a fixed trajectory[59]; the joint optimization of UAV trajectory, acceleration, and velocity[60]; the trade-off between performance improvement and energy consumption[61].

3 Key Technologies in Green AGIHN

How to realize energy-efficient network collaboration and integration of heterogeneous networks in AGIHN is one of the keys to SAGIN. In this section, several promising technologies for harvesting energy and reducing energy consumption in AGIHN are analyzed.

3.1 Energy Harvesting Technology

Energy harvesting technologies are promising approaches to prolonging battery life and providing extra power in green communications by collecting external energy resources such as light, heat, electromagnetic, and mechanical. Wireless power transfer (WPT) and SWIPT are two energy harvesting technologies for transporting energy with electromagnetic energy. WPT is a basic energy harvesting technology while SWIPT is an energy harvesting technology that integrates WPT and the communication function, i.e., SWIPT can simultaneously transmit information signals while transporting electromagnetic energy.

Leveraging WPT and SWIPT in AGIHN can realize remote charging and mutual charging among aircrafts. However, the mutual energy transport definitely causes increased energy consumption. Traditional energy collection technologies such as solar and wind systems can be combined as a RF energy source to reduce consumption of non-green energy, which is a promising research direction for AGIHN. For example, charging LAPs with solar-powered satellites and HAPs can prolong the flight duration of LAPs and enhance the stability of aerial networking. Moreover, the LAPs can further charge each other by exploiting the benefits of LoS links and charge ground terminals with two-hop wireless energy transmission. In addition, leveraging IRS in SWIPT-assisted LAP system can simultaneously improve the network performance and enhance the energy transmission efficiency[38].

3.2 Cooperative Communications

Cooperative transmission can improve network performance by coordinating multiple diverse nodes to exploit the multiplexing gain and diversity gain. In AGIHN, coordinating multiple aerial nodes as information signal sources can provide significantly improved capacity and coverage performance with LoS links, flexible-changed topology, and adaptive resource coordination. The transmission power of aerial nodes can be greatly reduced due to the decreased path loss fading. Further, coordinating multiple aerial nodes as electromagnetic energy sources can realize rapid power charging and network restoration and reconstruction. Coordinating aerial nodes and ground BSs can provide more energy-efficient transmissions than coordinating only ground BSs due to the reduced transmission power of aerial nodes and the exemption of energy consumption of BS infrastructures. Especially, the energy efficiency of cell edge users can be significantly improved by deploying periodic UAVs at the edge of ground BSs and periodically coordinating UAVs-enabled BSs or relays with the ground BSs[62].

Coordination and cooperation of ground nodes and aerial nodes can realize improved energy efficiency in AGIHN. However, the high-dynamic network topology, non-uniform data traffic, and random perturbation of aerial platforms bring great challenges to the cooperative communications in AGIHN. The high-dynamic network topology introduces frequent disconnection and reconnections, which brings huge signaling overhead. Blockchain based access registration provides a way in reducing the signaling overhead[63]. Non-uniform data traffic brings challenges to the user scheduling and traffic load coordination among cooperative nodes, which further causes tradeoff between balanced traffic offloading and efficient energy consumption. The random perturbation of aerial platforms causes non-robust and inefficient transmission links between a pair of transceivers. Accurate estimation of platform perturbation, appropriate compensation for perturbation, and adaptive power allocation and beam adjusting are required for energy-efficient communications in AGIHN.

3.3 Integrating Intelligence into Green AGIHN

AI technologies, especially machine learning (ML) and big data analysis, are promising and widely acknowledged solutions to smart network control and network management. AI has already been applied in mobile networks from physical layer design to network layer control. Leveraging AI in 6G networks is an inevitable trend. In green AGIHN, AI can be applied in many aspects including intelligent architecture design, real-time network data analysis, flexible aerial platform control, secure aerial platform tracing, smart platform position, high-efficient energy harvesting, intelligent routing, intelligent caching and computing, intelligent sleeping and wake-up mechanisms, adaptive and efficient resource allocation and scheduling, etc.

Leveraging intelligence into AGIHN can realize enhanced energy efficiency by globally optimizing the network control and management. However, mechanisms adopted to realize intellectualization will bring additional energy consumption, especially for the intelligent network management through global control or massive data analysis. Therefore, energy-efficient intelligent network control and management mechanisms are required in green AGIHN.

4 Conclusions

Facing the high complexity and diversity of future networks and the proliferation of wireless devices, AGIHN is considered as a cost-effective approach to ubiquitous coverage and ultra-high throughput. With the increasing scarcity of natural resources and complexity of the radio environment, it is urgent to solve the problems of green AGIHN to reduce energy consumption and to improve energy efficiency. In this paper, we first introduced the integration of AGIHN and 6G networks. Then, the challenges of green AGIHN were analyzed from the aspects of green terrestrial network and green aerial network. Following the analysis, several promising green technologies that can be employed in AGIHN have been discussed.

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