

## Analysis of Wireless Backhaul Networks Based on Aerial Platform Technology for 6G Systems

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**Abstract:** As next generation communication technologies emerge, new high data rate applications and high-definition large-screen video streaming have become very popular. As a result, network traffic has been increasing so much that existing backhaul networks soon will not be able to support all traffic demands. To support these needs in future 6G mobile systems, the establishment of an additional backhaul wireless network is considered essential. As one of the solutions, a wireless backhaul network based on an aerial platform has been proposed. In order to explore the potential of aerial platforms as wireless backhaul networks, in this paper, the categories for wireless backhaul networks based on aerial platforms are investigated. This paper includes a survey of the definitions and characteristics of low altitude platforms (LAPs) and high altitude platforms (HAPs), as well as channel models according to the atmosphere. For wireless backhaul network designs based on aerial platforms, altitude and platform selection options, deployment options, energy issues, and security based on target location and performance were considered in the analysis and investigation.

**Keywords:** Wireless backhaul network, aerial platform, high altitude platform, low altitude platform.

### 1 Introduction

As 5th generation mobile networks are being deployed worldwide, mobile devices and the demand for various applications are increasing rapidly. In addition, the number of various sensors (including data from internet of things (IoT) devices) and the amount of mobile data focused on backhaul networks are increasing rapidly. Especially, mobile traffic is expected to grow by more than 50% annually from 2015 to 2020 [Cisco Visual Networking Index (2019)]. This trend of mobile traffic increase is expected to grow even more in the future, which is one of the major tasks that 6G mobile networks need to deal with.

Designing a new backhaul network for 6G is one of the core areas of 6G networks. Due to the increased user equipment (UE) data rate requirements and the massively growing number of autonomous systems using the wireless mobile network, when the number of

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serving UEs and capacity limitation of existing wired backhauled are considered, new methods to overcome bottlenecks in the backhaul network have been recently proposed. A backhaul network is a network that provides connectivity from the base stations (BSs) (e.g., 4G eNBs and 5G gNBs) to the core network. It greatly affects the performance of the entire network and it is one of the key challenges of 5G and 6G networks [Chia, Gasparroni and Brick (2009)]. The backhaul network is expected to cost more than half of the price of building a small cell network. However, investments cannot be avoided as the backhaul network will provide the core connectivity for the 5G network. Therefore, a cost-efficient backhaul design is required [Wang, Hossain and Bhargava (2019)].

Wireless backhaul networks based on aerial platforms include low altitude unmanned aerial vehicles (UAVs) and high altitude UAVs, aircrafts, or airships, where various new designs for 5G and 6G backhaul networks is an emerging research area [Asadpour, Bergh, Giustiniano et al. (2014); Valavanis and Vachtsevanos (2014)]. A backhaul based on an aerial platform that utilizes various wireless signals (e.g., radio frequency (RF), mmWaves, microwaves, lasers, and free space optics (FSO)) provides autonomy, flexibility, and a broad range of application domains compared to optical fiber backhaul networks commonly used [Mozaffari, Saad, Bennis et al. (2019)]. The following are the advantages of wireless backhaul based aerial platforms.

**Cost efficiency:** In order to accommodate the surging traffic of the existing wired backhaul, it is necessary to build additional wired networks on the ground to increase the service capacity, which leads to a significant increase in overall costs (i.e., CAPEX, OPEX). In contrast, backhauled based on aerial platforms takes a very short time to install (unlike the wired backhauled), and does not require a significant installation cost.

**Flexibility:** Aerial platforms do not require much time to install, and can be expanded freely as traffic demands increase. In addition, it is easy to withdraw the network as traffic demands decrease. This means that it can provide flexible scalability for increasing network capacity.

**Easy to deploy:** Aerial platforms can be deployed regardless of ground characteristics, which means that communications can be provided smoothly even in areas where traditional backhauled are difficult to build and install, such as, mountains, jungles, and deserts. Rapidly deployable communications are also one of the key elements of public safety and military communications, which is why the military is attempting to use aerial platforms in a variety of ways, including reconnaissance and surveillance communications.

**Line of sight (LoS) propagation:** FSO using mmWave spectrum or optical wireless communication (OWC) has the ability to satisfy the high data rate requirements for broad bandwidth services. However, these frequencies are more sensitive to blockage and fading than conventional RF signals, and require the transmitter and receiver to maintain LoS for smooth communication. Unlike terrestrial networks where there can be many obstacles between the transmitter and the receiver, using vertical communication utilizing an aerial platform makes it easy to maintain LoS propagation between the transmitter and receiver.

In this paper, an overview of wireless backhaul network technologies is provided, which includes a review of theoretical studies and use cases based on aircrafts including low altitude platforms (LAPs), such as UAVs, and high altitude platforms (HAPs) that use UAVs as well as unmanned or manned aircrafts and airships.

## **2 Background**

### ***2.1 Low altitude platform (LAP)***

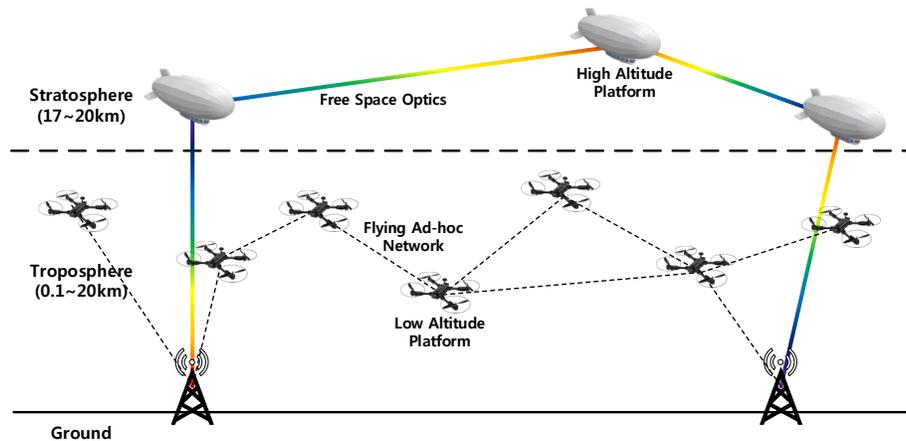
In Fig. 1, LAPs are the aerial platforms, which can be formed with UAVs, drones, quadcopters, and/or balloons (e.g., blimps) that are located at an altitude of 0.1~20 km. Compared with HAPs, LAPs may have relatively lower capacity and payload support, and the autonomy and performance may vary depending on the size and form of the LAPs. Due to the relatively small size of LAPs, LAPs commonly operate on lithium-ion batteries and their operation time is about 10~40 minutes, depending on the battery capacity, mobility pattern, and payload weight [Chandrasekharan, Gomez, Al-Hourani et al. (2016)].

UAVs are one of the platforms that are getting the most attention recently, because they can be used in various applications, such as, surveillance, search, and fire monitoring. Communication services can also use UAVs as relay nodes to improve the performance of the existing cellular networks [Guo and O'Farrell (2013)]. For this purpose, relaying to provide a wireless link between BSs or constructing an ad-hoc network using multiple UAVs based on flying ad hoc network (FANET) technology has been proposed [Bekmezci, Sahingoz and Temel (2013); Chen, Zhao, Ding et al. (2018)]. FANETs that use multiple UAVs can offer wider coverage, increased redundancy, and increased survivability than using a single UAV. In addition, UAV based communication is drawing attention because it can be deployed much faster than existing networks in emergency scenarios due to remote areas or natural or man-made disasters [Rahman, Kim, Cho et al. (2018)].

### ***2.2 High altitude platform (HAP)***

In Fig. 1, HAP is the aerial platform using unmanned or manned aircrafts, airships and balloons operating in quasi-stationary positions in the stratosphere at an altitude of about 17~22 km. HAPs have the advantages of terrestrial communication and satellite communication. HAPs can monitor a larger area than LAPs or terrestrial networks. HAPs have more endurance which enables them to operate for days or weeks through the convergence of gasoline engines and solar energy using larger payloads. In addition, HAPs have much shorter propagation delay and much less expensive OPEX costs than satellite communication, and can effectively conduct deployment of aerial platforms much faster.

In fact, many companies and countries have conducted a variety of studies that leverage the benefits of HAP, where Google's Loon and Facebook's Aquila are the most representative projects. In project Loon, a balloon is launched to provide LTE connectivity up to 20 km, supporting Internet services in rural and remote areas that are not connected to a network [Google (2017)]. Facebook Aquila was developed in collaboration with Facebook and Airbus, aimed at using HAP relay stations to provide Internet access to remote areas [Facebook (2017)].



**Figure 1:** Wireless backhaul networks based on aerial platforms

### 3 Channel modeling techniques

5G and 6G systems require significantly high data rates, and as a result, more bandwidth is required. As a solution for this, higher frequency band signals, such as, mm Waves or optical communication signals can be used. Especially, FSO type OWCs that use optical signals with near infrared (IR) wavelengths of 750~1600 nm are commonly used for point-to-point links on the ground or for ultra-long connectivity between HAPs. This is why FSO technology receives much attention as a solution for backhaul bottleneck issues. With the development of light emitting diode (LED) technology that can transmit high frequency light and dark scintillation signals, visible light communication (VLC) systems, including FSO, are drawing attention as a new type of green communication technology [Zhang, Chen and Jin (2019)]. Unlike conventional RF signals, FSO signals have the advantage of being useable unlicensed, as well as being directional, immune to electromagnetic interference, not easily interceptable, and can provide high data rates up to several hundreds of kilometers. However, unlike RF signals, it has a disadvantage of being affected by atmospheric conditions. Typically, the factors affecting the performance degradation on FSO communication include the losses due to atmospheric factors and the losses due to misalignment between the FSO transmitter and receiver.

#### 3.1 Terrestrial channel modeling

In this chapter, channel models for terrestrial, LAPs, HAPs, and channel characteristics between LAPs are introduced. In the troposphere near the ground, there is more air than the stratosphere. As a result, unlike stratospheric channel models, attenuation due to air and weather can influence the signal significantly.

##### 3.1.1 Attenuation factor

The attenuation from atmospheric factors consists of absorption, scattering, and turbulence. Absorption loss occurs when photons within FSO beams collide with gaseous molecules, while scattering loss occurs when FSO beams collide with the particles in the

atmosphere. In Alzenad et al. [Alzenad, Shakir, Yanikomeroğlu et al. (2018)], Absorption loss is negligible compared to scattering loss, and scattering loss depends on weather factors, such as, snow, rain, and fog. Especially, compared to snow and rain with particle sizes larger than the wavelength, scattering losses can be more significant due to fog and haze. One of several models to express attenuation by fog or haze is the Kruse model, which is used in several FSO channel analyzers [Alzenad, Shakir, Yanikomeroğlu et al. (2018); Grabner and Kvicera (2010); Nadeem, Kvicera, Awan et al. (2009)]. A key parameter in the Kruse model is  $L_{sca}$ , which represents the attenuation in dB

$$L_{sca} = 4.34 \left( \frac{3.91}{V} \left( \frac{\lambda}{\lambda_0} \right)^{-\delta} \right) d \quad (1)$$

where  $V$  is the visibility range in kilometers,  $d$  represents the distance in kilometers,  $\lambda_0$  is the visibility range reference (e.g., 550 nm),  $\lambda$  is the transmission wavelength (in nm), and  $\delta$  is the size distribution of the scattering (which has different values based on the range of  $V$ ) as presented in Eq. (2).

$$\delta = \begin{cases} 1.6 & V \geq 50 \text{ km} \\ 1.3 & 6 \text{ km} \leq V < 50 \text{ km} \\ 0.585V^{1/3} & V < 6 \text{ km} \end{cases} \quad (2)$$

### 3.1.2 Turbulence

Most of the atmospheric loss is caused by turbulence, which constitutes different channel models according to the turbulence intensity. The intensity of the turbulence is mainly expressed by the altitude-dependent refractive index structure parameter  $C_n^2$  of the Hufnagel-Valley (H-V) model [Muhammad, Kohldorfer and Leitgeb (2005)].

$$C_n^2(h) = 0.00594 \left( \frac{v}{27} \right)^2 (10^{-5}h)^{10} \exp\left(\frac{-h}{1000}\right) + 2.7 \times 10^{-16} \exp\left(\frac{-h}{1500}\right) + A \exp\left(\frac{-h}{100}\right) \quad (3)$$

In Eq. (3),  $v$  is the root mean square of wind speed in m/s,  $h$  is altitude in m, and  $A$  is the nominal value of  $C_n^2(0)$ , which has the value of  $1.7 \times 10^{-14} \text{ m}^{-2/3}$ .

Depending on the size of  $C_n^2$  (e.g., strong turbulence of  $10^{-13} \text{ m}^{-2/3}$  or more, moderate turbulence of  $10^{-15} \text{ m}^{-2/3}$ , and weak turbulence of  $10^{-17} \text{ m}^{-2/3}$  or less), consideration should be given to the characteristics and properties of the channel model, such as, log-normal distribution, or gamma-gamma distribution. The log-normal distribution, which is mainly used in FSO channel models, is suitable in the case of fluctuation due to weak turbulence [Andrew, Phillips and Hopen (2001)]. When the intensity of the optical wave  $I$  is a random variable and the normalized variance of  $I$ , referred to as the scintillation index, is  $\sigma_I^2 = (E(I^2) - E(I)^2)/E(I)^2$ , the probability density function (PDF) of the log-normal distribution can be expressed as

$$f_{LN}(I) = \frac{1}{\sqrt{2\pi\sigma_I^2} I} \exp\left(-\frac{(\ln(I/I_0) + \sigma_I^2/2)^2}{2\sigma_I^2}\right) \quad (4)$$

where  $I_0$  is the irradiance in the absence of turbulence.

The gamma-gamma distribution is constructed based on the doubly stochastic theory using two gamma distributions. It can reflect the scintillation effect from weak turbulence

to strong turbulence, which cannot be handled in a log-normal distribution. The PDF of the gamma-gamma distribution is expressed as follows

$$f_{\Gamma\Gamma}(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\left(\frac{\alpha+\beta}{2}\right)-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta}I) \quad (5)$$

where  $K_n(\cdot)$  is the modified Bessel function of the second kind with order  $n$ ,  $\Gamma(\cdot)$  is the gamma function,  $\alpha$  and  $\beta$  respectively represent the effective number of large and small scale eddies of the scattering process, which are given below.

$$\alpha = \left[ \exp\left(\frac{0.49\sigma_I^2}{(1+1.11\sigma_I^{12/5})^{7/6}}\right) - 1 \right]^{-1} \quad (6)$$

$$\beta = \left[ \exp\left(\frac{0.51\sigma_I^2}{(1+0.69\sigma_I^{12/5})^{5/6}}\right) - 1 \right]^{-1} \quad (7)$$

The Malaga distribution is a relatively new statistical model designed to be applied in all irradiance conditions [Jurado-Navas, Garrido-Balsells, Paris et al. (2011)]. The Malaga distribution can express most statistical models, such as, log-normal and gamma-gamma by setting variables inside the model, and can be applied to from weak turbulence to strong turbulence situations. The PDF of the Malaga distribution can be described as

$$f_{\mathcal{M}}(I) = A \sum_{k=1}^{\beta} a_k I^{\frac{\alpha+k}{2}-1} K_{\alpha-k}\left(2\sqrt{\frac{\alpha\beta I}{\gamma\beta+\Omega'}}\right) \quad (8)$$

$$A \triangleq \frac{2\alpha^{\frac{\alpha}{2}}}{\gamma^{1+\frac{\alpha}{2}} \Gamma(\alpha)} A^{(G)} \left(\frac{\gamma\beta}{\gamma\beta+\Omega'}\right)^{\beta+\alpha/2} \quad (9)$$

$$a_k \triangleq \binom{\beta-1}{k-1} \frac{1}{(k-1)!} \left(\frac{\Omega'}{\gamma}\right)^{k-1} \left(\frac{\alpha}{\beta}\right)^{k/2} (\gamma\beta + \Omega')^{1-\frac{k}{2}} \quad (10)$$

where  $\alpha$  is a positive parameter related to the large-scale cells as in the gamma-gamma distribution, and  $\beta$  is a natural number. In (8),  $\Omega' = \Omega + 2b_0 \rho + 2\sqrt{2b_0\Omega\rho}\cos(\phi_A - \phi_B)$  is the average power from the coherent contributions, where  $\Omega$  is the average power of the LoS component,  $2b_0$  is the average power of the total scatter components,  $\rho$  expresses the amount of scattering power coupled to the LoS component, and  $\phi_A$  and  $\phi_B$  are respectively the deterministic phases of the LoS and the coupled-to-LoS components.

In addition,  $\gamma$  denotes  $2b_0(1-\rho)$  and  $\binom{\beta}{k}$  is a binomial coefficient [Jurado-Navas, Garrido-Balsells, Paris et al. (2011)]. In addition, there are various channel models, such as the negative exponential model and K-distribution. The negative exponential model is suitable for very strong turbulence [Al-Habash, Andrew and Phillips (2001)] and the K-distribution model is for strong turbulence, which is composed of a conditional negative exponential distribution and gamma distribution [Jakeman and Pusey (1978)].

### 3.1.3 Misalignment loss

In this subsection, we discuss misalignment loss, which has a significant effect on optical signal propagation. The misalignment error is caused by vibration and beam wandering at the transmitter and receiver. Since the misalignment loss is based on how well the aligned

beam of the transmitter and the receiver transmits, the beam width, fluctuation of the transmitter or receiver, and the size of the receiver lens need to be considered [Mai and Kim (2019)]. To identify the link loss caused by the misalignment loss, it is necessary to check the radial distance  $r$  between the center of the laser beam and the receiver aperture. The PDF of  $r$  can be expressed as Eq. (11).

**Table 1:** Summary of channel model according to turbulence intensity

Channel model	Turbulence condition	PDF
Log-normal	Weak	$f_{LN}(I) = \frac{1}{\sqrt{2\pi\sigma_I^2} I} \exp\left(-\frac{(\ln(I/I_0) + \sigma_I^2/2)^2}{2\sigma_I^2}\right)$
K	Strong	$f_K(I) = \frac{2\alpha^{\frac{\alpha-1}{2}}}{\Gamma(\alpha)} I^{\frac{(\alpha-1)}{2}} K_{\alpha-\beta}(2\sqrt{\alpha I})$
Negative exponential	Very strong	$f_{NE}(I) = \frac{1}{E(I)} \exp\left(-\frac{I}{E(I)}\right)$
Gamma-gamma	Weak to strong	$f_{\Gamma\Gamma}(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta)}{2}-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta I})$
Malaga	Weak to strong	$f_{\mathcal{M}}(I) = A \sum_{k=1}^{\beta} \alpha_k I^{\frac{\alpha+k}{2}-1} K_{\alpha-k}\left(2\sqrt{\frac{\alpha\beta I}{\gamma\beta + \Omega'}}\right)$

$$PDF_r(r) = \frac{r}{\sigma_r^2} \exp\left(-\frac{r^2}{2\sigma_r^2}\right) \tag{11}$$

where  $\sigma_r$  is the standard deviation of  $r$ . When the gaussian beam at the transmitter Tx has a radius of  $w_z$ , and  $a$  is the radius of the beam at the receiver, the pointing error loss,  $h_p$ , can be expressed as in Eq. (12) [Dabiri, Sadough and Khalighi (2018); Farid and Hranilovic (2007)]

$$h_p \simeq A_0 \exp\left(-\frac{2r^2}{w_{zeq}^2}\right) \tag{12}$$

where  $= \sqrt{\pi}r/(\sqrt{2}w_z)$ ,  $A_0 = (\text{erf}(v))^2$  denotes the maximal fraction of the collected intensity, and  $w_{zeq}^2 = w_z^2\sqrt{\pi}\text{erf}(v)/2v\exp(-v^2)$  represents the equivalent beam width.

### 3.2 HAP channel modeling

Since these various factors significantly affect the performance of cross-platform FSO communications in the atmosphere, HAP based FSO communication has recently been considered to be a more effective method than LAP in reducing the total loss, due to the sparsity of air in the stratosphere compared to the atmosphere where LAPs are interconnected. The factors that affect the performance degradation in FSO communication between HAPs mainly includes errors caused by misalignment between the optical transmitter and receiver, due to non-negligible atmospheric turbulence and scattering in the stratospheric level, compared to the ground level. For detailed analysis of the misalignment error, some recent research papers have tried to accurately model the path loss due to the angle of arrival (AoA) fluctuation and pointing errors.

In Huang et al. [Huang and Safari (2017)], a theoretical model on fading caused by turbulence-induced AoA fluctuation with a limited field-of-view (FoV) is presented, as well as an expression of outage probability for both coherent and direct detection systems are investigated. Furthermore, Dabiri et al. [Dabiri, Sadough and Khalighi (2018)] analyzed and derived the statistical Ground-to-UAV, UAV-to-UAV, and UAV-to-Ground channel models including the PDF and cumulative density function (CDF) of link loss in the presence of atmospheric turbulence, AoA fluctuation, and pointing error. It also provides an analytical expression on the outage probability. In addition, Mai et al. [Mai and Kim (2019)] tried to loosen the oversimplification of the AoA fluctuation link loss model from earlier studies by utilizing a Gaussian pattern on the diffracted beam to improve the theoretical model of AoA fluctuation link loss. The authors also derive closed-form expressions on the outage probability and propose an adaptive beam control technique to mitigate the effects of AoA fluctuation and pointing errors.

## **4 Design considerations**

### ***4.1 Optimal altitude conclusion for aerial platforms***

There are some consideration issues when constructing a network using multiple aerial platforms. First, you need to set the altitude and platform type. Unlike wired backhauls, which are fixed on the ground, aerial platforms exist above ground/sea level, and therefore require three-dimensional coordinates, which include altitude as well as two-dimensional longitude and latitude location values. Internet service providers (ISPs) will need to decide whether to use LAP or HAP aerial platforms or satellite communication. This may depend on the size of the target area and the type of services used. LAP is appropriate for providing monitoring, communications, and surveillance services for relatively small areas. HAP may be more suitable for relatively large areas. In the case of LAPs, UAVs located in the troposphere need to consider turbulence as well as LAP communication signal attenuation and interference both in the vertical ground-to-UAV channel and the horizontal UAV-to-UAV channels. On the other hand, in the case of HAPs, since the communication channel between HAPs in the stratosphere are very stable, the challenge in performance will be determined mostly by the vertical ground-to-UAV channel conditions (which is much longer than the vertical ground-to-UAV channel of LAPs), rather than the high altitude horizontal UAV-to-UAV channel conditions. When constructing a backhaul LAP network using UAVs, as the altitude of the UAV increases, it is imperative to increasing the pass loss, since the turbulence will increase in the air-to-ground communication. Whereas in the same case, the LoS connection also increases since it is less affected by the atmospheric conditions.

Most of the research papers on the deployment of aerial platforms focus mainly on the deployment of LAP UAVs, because the coverage of LAPs is narrower than HAPs, which manages larger areas of about 200 km radius or longer [Alsamhi and Rajput (2015)]. First, various methods to determine the optimal altitude and location of the UAVs have been proposed. In Mozaffari et al. [Mozaffari, Saad, Bennis et al. (2016)], optimal UAV positioning is considered in stationary LAP environments using quadrotor UAVs. UAV deployment is controlled by defining the relationship between the required size of coverage, altitude, antenna beamwidth, as well as the number and location of the UAVs.

In this process, circle packing theory was used to calculate the maximum total coverage when considering the coverage radius of each UAV and the total number of UAVs. From this, optimal UAV deployment can be derived that does not overlap the coverage as much as possible between UAVs. In Chen et al. [Chen, Feng and Zheng (2018)], optimal UAV placement for maximum reliability has been studied. An optimal altitude with the best relaying performance was derived by numerical search considering total power loss, overall outage, and overall bit rate.

#### **4.2 Deployment and relaying algorithms for aerial platform**

The setup and layout of the number of UAVs and the relay technique should be considered. Optimal UAV deployment for maximum coverage performance should be derived in consideration of interference between received signals of the UAVs [Mozaffari, Saad, Bennis et al. (2015)]. Therefore, appropriate UAV deployment should be designed in consideration of the altitude of the UAVs and signal interference between the UAVs. However, with the ever-changing channel environments and minimum transmit power requirements, the required number of UAVs and coverage performance should change, resulting in the coverage area to be different continuously. Therefore, by analyzing channel parameters changing in real-time, it is necessary to derive the optimal number of UAVs to deploy that will satisfy the required overall coverage and time performance. UAV coverage also varies according to altitude as well as 2D placement, so 2D placement of UAVs should be considered at the same altitude [Alzenad, El-Keyi, Lagum et al. (2017)]. UAV relays have the advantage of placing the UAV in the optimal location to maximize network performance. In addition, UAV mobility should be considered because network performance varies according to the service method or cooperative method during movement [Fotouhi, Qiang, Ding et al. (2019)].

Once the optimal altitude and positions of the UAVs are determined, a method to relay the signals through the UAVs is needed. In Zeng et al. [Zeng, Zhang and Lim (2016)], a moving UAV relaying system has been studied for cost efficiency improvement and performance enhancement, where the relay trajectory and power allocation of the source and relay nodes are optimized to achieve a throughput maximized performance. In Han et al. [Han, Baek and Han (2018)], a multi-layer UAV relay system has been studied. In order to maximize the average data rate of the UEs, the minimum number of transmit time slots, the minimum number of UAVs and UAV placements were derived using the minimum UE data rate. According to the change of channel state information between UAVs, the authors of Zeng et al. [Zeng, Huangfu and Liu (2019)] propose a relay mode selection scheme for full duplex and half duplex channel access systems. In Rahman et al. [Rahman, Kim, Cho et al. (2018)], an UAV positioning algorithm that can be deployed at an SDN controller for throughput maximization in disaster area multi-hop UAV networks is proposed. The proposed algorithm considers the requirement of each link flow and determines the position of each UAV among dedicated candidate positions based on the tabu search scheme. Since this work only considers traditional IEEE 802.11 based RF communication between LAPs, the proposed algorithm may be further utilized to UAV deployment algorithms considering HAP based FSO communication in the future work.

### **4.3 Energy efficient aerial platform**

Finally, the energy of the aerial platform needs to be considered. Since UAVs have limited battery capacity and consume power continuously through communication and mobility, it is necessary to maximize the lifetime of the UAVs by minimizing their power consumption [Fotouhi, Qiang, Ding et al. (2019); Yong, Zhang and Lim (2016)]. At this time, realistic UAV deployment cannot be achieved without considering the energy of the UAV, and research for energy-efficient UAV deployment is also in progress. In Ruan et al. [Ruan, Wang, Chen et al. (2018)], a multi-UAV coverage deployment model is proposed to overcome the energy shortage problem when using stationary LAPs. Based on the exact potential game, an algorithm was designed to combine multiple UAV environments with a coverage probability function. The proposed model was proved to be coverage maximized and energy efficient, using the existence of a Nash equilibrium point. In Li et al. [Li, Ni, Wang et al. (2016)], an UAV system considering the energy efficiency has been studied. In order to minimize the maximum energy consumption of UAVs, the packet scheduling process of cooperative UAVs is optimized using a low complexity suboptimal strategy. In Cho et al. [Cho and Ryoo (2018)], the authors designed a FPGA and CPU board for UAVs that can operate at low power and conduct target tracking in any environment.

### **4.4 Security on aerial platforms**

Commercial use of aerial platforms, including communications over backhaul networks, requires the use of hovering over a city, but many regulations prohibit flying aerial platforms (including UAVs) over city areas for safety reasons. To overcome this, it is necessary to make sure that aerial platforms are extremely reliable, robust, and are equipped with backup safety functions to avoid crashing into populated areas. Once this type of security mechanism is accomplished, urban area deployment can be considered.

For wireless control of the UAVs, RF and FSO communication systems have to be used.

**Table 2:** Summary of design considerations

Aspect	Ref.	Main contribution
Optimal altitude	[Mozaffari, Saad, Bennis et al. (2016)]	Optimization of the number of UAVs and UAV altitude to maximize the total coverage
	[Chen, Feng and Zheng (2018)]	Optimization of UAV altitude and placement as a relaying station using channel models, total power loss, overall outage, and overall bit rate
Deployment and relaying	[Zeng, Zhang and Lim (2016)]	UAV-enabled mobile relay trajectory and the source/relay power allocations to maximize the throughput
	[Han, Baek and Han (2018)]	Novel UAV deployment algorithm to maximize the throughput of UEs while guaranteeing a seamless communication service to isolated UE
	[Rahman, Kim, Cho et al. (2018)]	UAV positioning algorithm for throughput maximization in disaster area multi-hop UAV networks
Energy efficient	[Li, Ni, Wang et al. (2016)]	Packet scheduling algorithm of cooperative UAVs to minimize the maximum energy consumption of UAVs
	[Ruan, Wang, Chen	Multi-UAV energy-efficient coverage deployment

	et al. (2018)]	algorithm based on spatial adaptive play for coverage maximation and power control
Security	[Reyes, Gellerman and Kaabouch (2015)]	Study of cognitive radio technology for jamming detection
	[Yang, Wang, Geraci et al. (2015)]	Survey of wireless physical layer security
	[Li, Zhang, Zhang et al. (2019)]	Optimization of flying trajectory and transmit power for LoS security problem
	[Wang, Feng, Chen et al. (2019)]	Study of UAV swarm and PLS through power allocation technology

FSO communication systems enhance wireless network connectivity using lasers or light beams, which support very high data rates. Contrary to conventional RF signals, they use less power and support higher levels of security and signal bandwidth. In particular, FSO provides higher levels of security, because it is difficult for eavesdroppers to intercept the highly directional optical signals over the LoS communication link between optical transmitter and receiver. However, FSO has technical difficulties caused by the dynamic environment, such as, pointing error between the control center and the moving UAV. This has led to the emergence of a mixed RF and FSO relaying network that combines the advantages of both RF and FSO systems according to their mission objectives [Soleimani-Nasab and Uysal (2016)]. In such RF and FSO hybrid networks, the security requirement should include hybrid wireless network security functions and procedures.

The low cost, high mobility, and ease of operation of UAVs enable hackers to use UAVs as a means of an attack. Malicious attackers can hinder UAV communication security through jamming or eavesdropping attacks using malicious UAVs. Attackers also try to attack legitimate UAVs without directly targeting the ground control station (GCS). In addition, since the uplink communication from the GCS to the UAV is the most important channel to control the UAVs, a high level of security is required for the GCSs. Since FSO communication can be performed only when the receiver is directly pointing at the transmitter, the threat of eavesdropping is lower than that of broadcasting-based RF communications. However, due to the low altitude flight of UAVs and the use of RF for UAV-to-UAV communication, existing wireless security solutions can be used. Many studies are underway to defend against malicious behaviors, such as, jamming and eavesdropping attacks. In Li et al. [Li, Zhang, Zhang et al. (2019)], the authors studied BSs and multiple eavesdroppers to solve the LoS security problem, which is one of the biggest challenges in UAV operations. By maximizing the worst-case secrecy rate (WCSR) of the system, the authors optimized the flying trajectory and transmit power to improve the security level of the UAVs. In Zeng et al. [Zeng and Zhang (2019)], methods to improve the security level of eavesdropping attacks on device-to-device communication systems (where receivers work in full-duplex (FD) mode) are proposed. The proposed system enables honest users to receive their useful information and transmit jamming signals to the eavesdropper simultaneously. In Zhang et al. [Zhang, Ding, Wu et al. (2019)], a system that detects abnormal power emission, which can seriously affect UAV security was studied. The authors have formulated a mathematical formula through a cloud based drone surveillance framework and propose a method for

optimizing detection using the Neyman-Pearson test criterion. In Sedjelmaci et al. [Sedjelmaci, Senouci and Ansari (2017)], intrusion detection and attacker ejection, which are among the main issues of UAV security technology, were studied and the Bayesian game model is used to defend against lethal attacks by studying a framework that increases the detection performance and lowers false positive rates. In addition, there are many studies that can improve the UAV security level by combining various technologies. In Reyes et al. [Reyes, Gellerman and Kaabouch (2015)], through a system based on cognitive radio (CR) technology, UAV security was improved by making jamming detection more efficient. In Singh et al. [Singh and Verma (2018)], the reliability of UAVs was calculated using trust parameters and malicious nodes were isolated by optimizing trust parameters and risk assessment using a genetic algorithm.

In conventional wireless security, communication based on cryptography is used based on a key based algorithm to authenticate users. The cryptographic key methods are the well-known security mechanisms, which are basically deployed at the upper layer of the communications protocols. The cryptographical key method includes a symmetric-key and asymmetric key based approach. Symmetric-keys are used to share secret keys between senders and receivers based on a pre-agreed specific encryption algorithm and encryption key. Asymmetric keys use a public key and private key structure. Senders can encrypt data using the receiver's public key to prevent eavesdropping by third parties. However, cryptography methods also have problems. If there is no authorized third party, there can be a potential threat that the key can be exposed by a man in the middle attack (MITM). To solve the MITM issue, additional security procedures can be added, but the complexity will increase due to the additional communication procedures [Conti, Dragoni and Lesyk (2016)]. In addition, the performance of security based on cryptography is determined by the key length and complexity of the encryption and decryption algorithm. However, adding complex cryptographic methods or equipment to the UAV to achieve a higher level of security may reduce the UAV aircraft's response time to control messages, driving capacity, or energy efficiency. If additional algorithms are included in the UAV side for security reasons, this may trigger a trade-off relationship with the UAV's performance side. Therefore, security designs should be light-weighted as possible, in order to minimize the performance degradation of the UAV, which is a very difficult security challenge.

#### ***4.5 Anti-drone using aerial platforms***

Recent drone strikes in Saudi Arabia have shown that military usage of UAVs is becoming a more serious issue than ever. In addition, since UAVs are controlled by the GCS, attacks against that GCS can directly influence all UAVs. UAV communication is divided into uplink communication from the GCS to UAV, UAV to UAV communication within the aerial platform, and downlink communication from the UAV to GCS. Uplink transmission packets include control message from the GCS to UAVs, where the functionality to prevent attacks (e.g., jamming or eavesdropper) in uplink communications is one of the main objectives of UAV security. In RF and FSO hybrid networks, because a majority of the data is exchanged over the broadband FSO links, security of the FSO links are important for data protection. Because FSO links are

vulnerable to blockage on the LOS signals, the GCS-to-UAV FSO links and the UAV-to-UAV FSO links are all attackable points-of-failure. Due to this vulnerability of FSO links, UAV and GCS control signals are commonly exchanged over the RF data links. RF links are less vulnerable to blockage but can be eavesdropped more easily than FSO links. Therefore, advanced security schemes to protect both RF and FSO data links need to be applied [Gupta, Jain and Vaszkun (2016)]. Therefore, security on the aerial platform must be considered both for the RF and FSO links as well as the LAP and HAP platform devices (e.g., GCSs and UAVs).

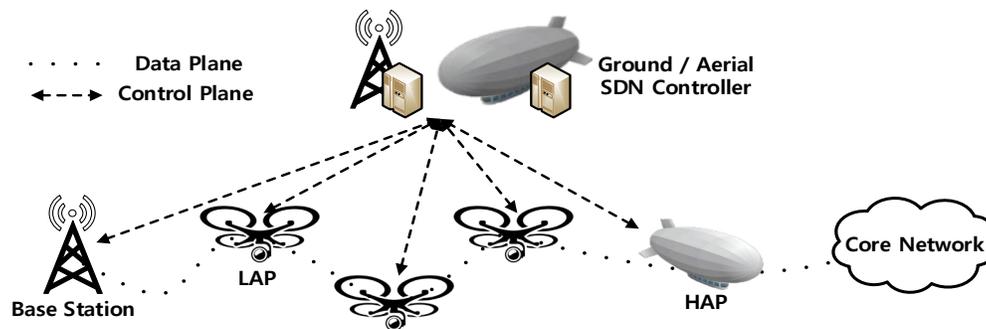


Figure 2: SDN based networks for aerial platforms

## 5 Research challenges

### 5.1 SDN framework

When constructing a network based on aerial platforms, a large amount of information (e.g., routing protocols, control of aerial flights, network programming, security mechanisms, and data flows into the aerial platform) need to be controlled appropriately. In addition, the motion of the UAV results in a continuous change in the wireless link and network topology, which requires adaptive control. As a solution to control such diverse and vast information, network management using software defined network (SDN) technology has been proposed [Ren, Wang, Ren et al. (2018); Zhang, Wang and Zhao (2018)]. Conventional SDN is a concept of constructing a software programmable infrastructure by separating the control plane and data plane in wired networks. But recent attempts to apply SDN technology to mobile networks (e.g., mobile ad hoc network (MANET) and vehicular ad hoc network (VANET)) are increasing [Detti, Pisa, Salsano et al. (2013); Ku, Lu, Gerla et al. (2014)]. SDN technology is expected to be fully applicable to FANETs (i.e., an ad hoc network using UAVs) in the near future.

The aerial platform is required to evolve into UAV gateways/routers with sufficient hardware and software capability to handle 5G and 6G functions, rather than a UAV providing only relay functionality [Nandiraju, Nandiraju, Santhanam et al. (2007); Xilouris, Batistatos, Athanasiadou et al. (2018)]. To have such capability, network configurations using SDN and network function virtualization (NFV) are essential. In particular, UAV based FANETs are very volatile unlike ground structures, because network topology changes occur frequently. Therefore, if SDN is used, it can help in dealing with frequent changes programmatically and automatically, and make path

selection and channel selection easier and faster [Gupta, Jain and Vaszkun (2016)].

SDN based UAV networks consist of an aerial BSs, UAVs which play the role of relay/forwarding nodes between BSs and SDN controllers for monitoring and controlling mobility, positions, and internal traffic of the UAV. Fig. 2 is a schematic diagram of a SDN based network on an aerial platform. In Fig. 2, the SDN controller can be located on the ground or in the air, and can communicate with adjacent UAVs to send and receive control signals. When constructing a SDN based aerial network, it is necessary to consider the location of the SDN controller, QoS requirement, and load balancing between the controller and relay/forwarding nodes [Zhao, Meng, Lu et al. (2018)]. In Bekmezci et al. [Bekmezci, Sahingoz and Temel (2013)], the HAP station is used for location sharing between the UAV nodes like the SDN aerial controller in Fig. 2. In addition, to enable higher mobility through the FANET, the UAV can accurately locate the neighbors through the HAP station. In addition, the network efficiency can be improved by using a location oriented directional MAC (LODMAC), which uses three directional smart beam antennas, to facilitate neighbor discovery and minimize head-of-line blocking problems. UAVs communicate directly with each other or through multi-hop forwarding. The SDN controller collects UAV network statistics and parameters, and makes optimal decisions through precise calculations.

### **5.2 Traffic prediction**

There are some papers that use real-time traffic monitoring in deploying aerial platforms [Chow (2016); Zhang, Mozaffari, Saad et al. (2018)]. Although, most UAV related studies are based on time invariant traffic, where timely and flexible UAV deployment is based on the demand of the end users, and also need to conduct predictions of traffic changes. In Zhang et al. [Zhang, Mozaffari, Saad et al. (2018)], a machine learning based scheme to arrange the UAVs by predicting traffic demands is proposed. In this paper, UAVs play the role of aerial BSs that predict whether the traffic of the cellular network exceeds the existing network capacity and then offloads the ground BS traffic through the UAV.

In addition, it is expected that network traffic prediction techniques, which have been used in recent network control schemes, can be applied to the aerial platform. In Zhang et al. [Zhang, Bai, Li et al. (2019)], the authors proposed an ensemble cascading prediction framework to perform the prediction of short-term traffic flows, which plays an important role in intelligent transportation systems (ITS). Such short-term traffic flows are fully applicable to UAV non-stationary environments as well as ITS applications. In Lu et al. [Lu, Zhou, Wu et al. (2016)], the authors proposed a traffic prediction technique in a large-scale wireless local area with highly uneven interference and throughput at airports, campuses, and highways. In Zhang et al. [Zhang, Huang and Li (2015)], prediction-based routing methods were proposed for opportunistic networks consisting of wirelessly connected nodes, such as, VANETs and MANETs. In this paper, the authors predicted node movement and corresponding link changes, where the prediction is expected to be applicable to UAVs based on FANETs.

### **5.3 Aerial base station**

In conventional research, UAV research focuses on what robots do, such as, navigation,

control, and autonomy, where communication issues are ignored or not considered [Mozaffari, Saad, Bennis et al. (2019)]. Recently, however, studies are being actively conducted considering that UAVs can serve as aerial BSs to supplement or replace existing cellular networks. In particular, a research aspect that is actively underway with next generation networks, is complex and real-time application services supported by network slicing and edge computing [Xilouris, Batistatos, Athanasiadou et al. (2018)].

Despite of this challenge, drone cells using drone BSs have been actively under way due to the strength to give agility and resilience in situations, such as, critical natural disasters, highly populated stadiums and concerts, as well as temporary unexpected traffic congestion locations. In Bor-Yaliniz et al. [Bor-Yaliniz and Yanikomeroglu (2016)], the authors suggest a drone-cell management framework (DMF) for drone cells and claim that next generation technologies, such as, cloud, big data, NFV and SDN will enable wireless networks to operate a higher level of quality of service (QoS).

**Table 3:** Summary of research challenges on aerial platforms

Aspect	Ref.	Main contribution relevant to aerial platforms
SDN	[Detti, Pisa, Salsano et al. (2013)]	Attempts to apply SDN to ad hoc networks, moving over time, such as VANET and MANET
	[Ku, Lu, Gerla et al. (2014)]	
	[Xilouris, Batistatos, Athanasiadou et al. (2018)]	UAV-based 5G network architecture, where UAV supports not only a simple relay node but also network slicing and virtualization
Traffic prediction	[Zhao, Meng, Lu et al. (2018)]	SDN based aerial network framework considering the location of the SDN controller, QoS requirement, and load balancing
	[Zhang, Mozaffari, Saad et al. (2018)]	Machine learning framework that enables predictive on-demand deployment of UAVs
Aerial BS	[Zhang, Bai, Li et al. (2019)]	Ensemble cascading learning of the extra-trees for short-term traffic flow prediction
	[Bor-Yaliniz and Yanikomeroglu (2016)]	An overview of multi-tier drone cell management framework
MEC	[Dong, He, Nan et al. (2015)]	Virtual multiple-input multiple-output (MIMO) transmission of interconnected HAP networks for the cloud storage
	[Motlagh, Bagaa and Taleb (2017)]	A survey of UAVs in IoT use cases, offloading of video data processing to a MEC node saving the energy of UAVs, and reducing the processing time
Blockchain	[Jensen, Selvaraj and Ranganathan (2019)]	Applying blockchain to UAV swarm systems to increase UAVs' security

**5.4 Multi-access edge computing**

HAP and LAP systems need to consider the limited energy and payload size/weight that can be supported by the UAVs. By offloading parts of the computations, the UAV operation time can be kept longer. To support such needs, multi-access edge computing (MEC) has been proposed as one of the key methods to assist computational offloading [Motlagh, Bagaa and Taleb (2017)].

The MEC based network structure is suitable for handling huge amounts of traffic and service requirements. MEC technology is also suitable to assist various emerging service types, such as, ITS and massive IoT [Kim and Kim (2018); Lee, Lee and Cho (2018)]. MECs can provide fast service support through cloud-computing capabilities at the edge of the network [Hu, Patel, Sabella et al. (2015)]. The edge of the network mainly refers to the BSs (e.g., 4G eNBs, 5G gNBs, and LAP/HAP GCSs), and data centers close to the radio access network (RAN). By offloading a variety of information, including video data from the UAVs to MEC nodes, data can be processed faster and more efficiently than when being processed on the UAVs. Such MEC network support can significantly ease the burden of the backhaul and core network [Luo, Nightingale, Asemota et al. (2015); Motlagh, Baggaa and Taleb (2017); Han, Maksymyuk, Bao et al. (2019)]. MEC technology can significantly help relieve limitation in computation capacity and the computing energy resources in current UAV base LAP/HAP networks. Due to these reasons, HAPs have been attracting attention as a platform for cloud services [Dong, He, Nan et al. (2015)]. The rapid increase in computing capacity of mobile devices and advances in battery technology (including wireless charging) suggest that aerial platforms (including UAVs) would need much MEC support in the near future [Li, Fei and Zhang (2019); Zhou, Wu, Sung et al. (2018)].

### **5.5 Blockchain**

There are also studies that focus on improving the security of UAVs using the latest blockchain technology and cryptography. In Jensen et al. [Jensen, Selvaraj and Ranganathan (2019)], security improvements using a blockchain have been studied. In order to defend against cyber-attacks targeting a large amount of data from the UAV, they proposed a framework incorporating blockchain technology, based on an immutable ledger scheme. In Lei et al. [Lei, Zhang, Lou et al. (2019)], the authors try to solve the security problem by combining a permissioned blockchain system with named data networking technology to detect internal attackers to solve the content poisoning problem, which is one of the major UAV security challenges.

### **6 Conclusion**

In this paper, a survey was conducted on wireless backhaul networks based on aerial platforms, one of the foundations of next-generation communication technology, which includes 6G networks. Classification according to altitude of aerial platforms, definitions and characteristics of HAP and LAP were explained. In addition, explanations to why VLC based FSO can be more effective as an aerial platform technology compared to traditional RF links (which are mainly used in existing wireless communications) and the related channel models are discussed. In addition, for aerial platform based wireless backhaul network design, it is shown that it is necessary to consider altitude, platform, deployment, and energy issues according to the target area, performance, and service requirements. Then, a survey of security issues is provided, which needs more attention than network equipment installed on the ground. We hope that this paper will yield better results for different types of problems in next generation networks.

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