High Altitude Platform Stations For Future Wireless Communication: A SURVEY

Seyyed Vahid Ziaratnia
Department of Electrical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran.
Email: vahidziaratnia@mshdiau.ac.ir

Reihaneh Kardehi Moghaddam*
Department of Electrical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran.
Email: r_k_moghaddam@gmail.com
ORCID: 0000-0002-5035-9455

Abstract:

Wireless telecommunication systems have rapidly developed their networking capability, enabling better and more advanced services for various wireless telecommunication applications. There are several methods of classifying wireless communication networks based on network usage, technology used, bandwidth, and frequency range. Despite the availability of satellite systems, they come with a few drawbacks such as high costs (for satellites and launch) and technical requirements for non-GEO satellite systems or the possibility of joining GEO satellite systems. Ground systems also have their own set of problems, such as being costly and having potential health and environmental risks. High Altitude Platform Station (HAPS) is a station located on an object at an altitude of 20 to 50 km and fixed relative to the ground. While they have brought a new set of problems, HAPS deployment is fast and incremental, maintenance is easy, and they can be reset and reassigned. The round-trip delay is less than 0.5s, and they can be environmentally friendly (solar). Generally, HAPS operates at an altitude of about 22km, which means a potential service area of over 200 km radius, depending on the altitude. In this paper, we propose a brief review of HAPS, its related technical aspects, and keys introduced by HAPS.

Index Terms: Wireless communication, High Altitude Platform System, transmitter, receiver, telecommunication

1. INTRODUCTION

The market's need for the use of wireless telecommunication is always changing and growing, and it provides many telecommunication services. Two issues of adequate coverage and high data transmission speed have been discussed in the design of modern wireless communication systems. Economic and scientific analyses indicate that this need increases because different public and private sectors in different organizations are dependent on modern technologies in wireless communication to improve and simplify telecommunication services and applications as much as possible. This need and request has led to the increasing production and use of satellite and terrestrial wireless telecommunication networks and has introduced technologies such as wide spectrum and multi-band to the world of telecommunications. On the other hand, these wireless communication methods cannot fully cover the needs of wireless communication in the future, and for this reason, telecommunication research departments in the military and commercial fields are looking for new ways to use the wireless communication spectrum to provide sufficient capacity for future telecommunication services and applications. Of course, the provision of high-capacity services faces a big challenge, and that is the limited radio frequency spectrum, and the more the demand for the growth of broadband services increases, the more the lack of spectrum is felt. To provide bandwidth to a large number of users, frequency reuse methods are usually used, which are based on the cellular telecommunication network architecture. Figure 1 shows an example of this hexagonal cell structure. In this structure, approximately in the center of each cell, there is a base station that uses a different frequency or set of frequencies compared to the neighboring cells, and this distinction is shown in the figure with color. Frequency reuse is done at certain intervals, which is a function of several factors such as the signal propagation environment and the ratio of the signal to the total noise and interference is acceptable. To increase the capacity, smaller cells with a larger number are usually used, which allows the frequency reuse method to be used more in a specific geographical area. This state is shown in Figure 1, Part B. This structure is called the microcell concept, which is used for areas with high user density. In the upper limit of this concept, there will be one cell for each user, which is not possible in terms of economic and environmental impact [1,2].

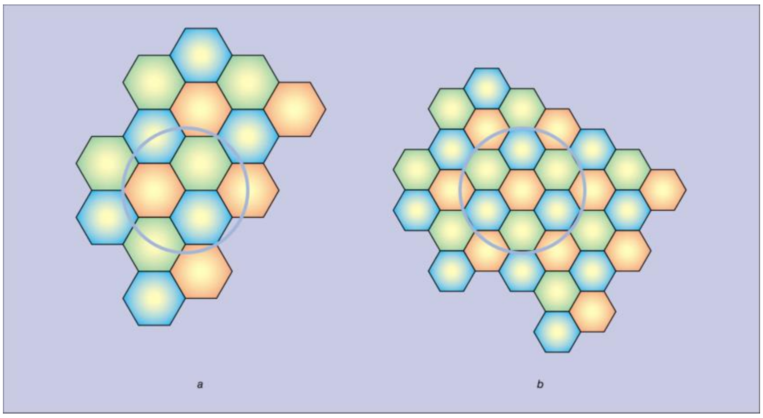


Figure 1- Cellular frequency reuse concept. In b the smaller cells provide greater overall capacity as frequencies are reused [3]

One solution is to move towards high-frequency spectrums in the millimeter wave range, which has the two advantages of a wider frequency spectrum and the possibility of providing very high bandwidths. Low-orbit satellites compensate for some of the problems and limitations of earth-orbit satellites, but the complexity of the hand-to-hand process in them is high. Also, to continuously cover an area, a large number of LEO satellites are needed, which is not economically feasible. The right solution lies in mobile aerial structures, which are flying telecommunication relays. High-altitude wireless communication, which relays information at a height between 17 and 22 km above the ground, offers a new solution for telecommunication system suppliers that can simultaneously measure satellite and terrestrial communication indicators. to have in himself. In this system, it is possible to publish direct views to users. An aerial structure can alone replace a large number of ground stations and at the same time not have structural, cost, and environmental limitations. In the following, we will have an overview of wireless communication methods. Then the high-altitude systems will be examined in terms of equipment, architecture, and overall structure. The applications of this type of system will also be examined. Despite the possibility of using satellite systems, there are clear disadvantages including high costs (satellites and launch) to technical requirements for non-GEO satellite systems or the possibility of joining GEO satellite systems. Ground also has special problems: expensive and in addition potential health and environmental risks are big problems. In [4] a high Altitude Platform Station (HAPS) is defined in the ITU Radio Regulations as a station located on an object at an altitude of 20 to 50 km and a fixed point relative to the ground, this new concept of wireless access shows some problems in wire while they bring many new problems. HAPS deployment is fast and incremental, maintenance is easy, and they can be reset and reassigned. The round-trip delay is less than 0.5s, and it can be environmentally friendly (solar).In general, there is an altitude of about 22km which means a potential service area of more than 200 km radius depending on the altitude[4,5].

In this article, the main goal is to review HAPS, in this direction, wireless communication will be reviewed first, and then we will discuss the components of the HAPS system, and its advantages and disadvantages will be compared with other methods.

2- An Overview of Wireless Communications

A telecommunication system comprises three main components: the transmitter, the receiver, and the telecommunication channel. For two-way communication between two points, A and B, they must use an intermediate medium, which is known as a wireless communication channel. The transmitter's primary function is to send a message through the telecommunication channel. Typically, the raw signal sent is unsuitable for transmission through the channel. Therefore, the transmitter converts the signal into a specific electrical signal, making it suitable for sending through the channel, a process called modulation. The transmitter also performs other tasks, such as filtering, amplification, and signal radiation [6,7] .

The telecommunication channel is the environment used to transmit information from the sender to the receiver. This environment can be telephone lines, open air, or water. Each environment has its obstacles and limitations, such as mountains, tall buildings, open water, vehicles, and even outer space can be obstacles of this type. Regardless of the transmission space, the signal gets lost and distorted due to the channel's interference [8,9]. The third component is the receiver, which receives the signal from the transmitter and processes it to convert it into the appropriate form [10]. The main step in this process is demodulation, which converts the signal from a form suitable for the channel to a form suitable for the receiving system. In addition to demodulation, this section also performs other activities, such as filtering, noise removal, and frequency reduction [11].

A telecommunication system is made up of three main components: the transmitter, the receiver, and the telecommunication channel. For two points, A and B, to communicate with each other using a telecommunication system, they need to use an intermediate medium known as a wireless communication channel [12-13].

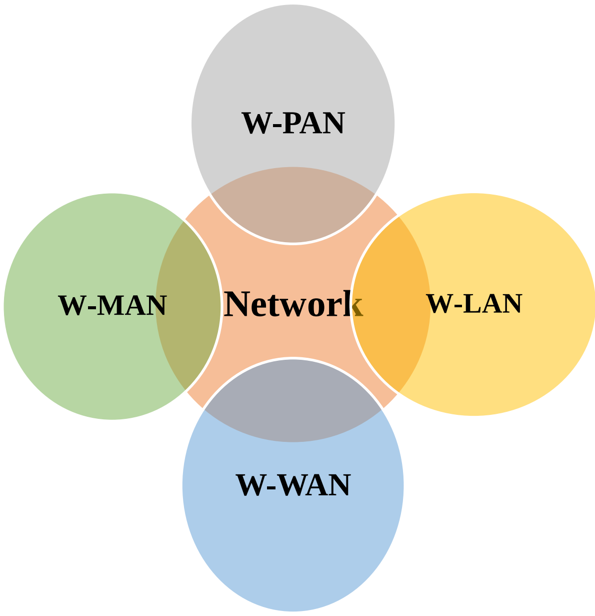
The primary function of the transmitter is to send a message through the telecommunication channel. However, the raw signal sent is usually unsuitable for transmission through the channel. Therefore, the signal is converted into a special electrical signal, and the transmitter makes it available in a form that is suitable for transmission through the channel. This process is called modulation. The transmitter also performs other tasks such as filtering, amplification, and signal radiation. The telecommunication channel is the environment through which information is transmitted from the sender to the receiver. This environment can be telephone lines, open air, or water. Each environment has its obstacles and limitations, such as mountains, tall buildings, open water, vehicles, and even outer space. Regardless of the type of data transmission space, the signal gets lost and distorted due to passing through the channel. The receiver is responsible for receiving the signal from the transmitter and processing it to convert the signal into the appropriate form. The main step in this process is the demodulation of the signal, which converts the signal from a form suitable for the channel to a form suitable for the system that is receiving the message. In addition to demodulation, other activities such as filtering, noise removal, and frequency reduction are performed in this section [1,4,14,15].

Table 1 -An overview of survey HAPS system

Reference	Year	Focus	Description
[16]	2005	Wireless architecture	Technical and architectural aspects of HAPS
[17]	2007	Project deployments	Basic concept of HAPS technology, applications
[1]	2008	Wireless architecture	The original concept of HAPS as an alternative to telecommunications
[18]	2009	Project deployments	HAPS projects and applications
[19]	2010	Optical links	A review of technologies, HAPS optical communication studies
[20]	2010	Spectrum management	A review of HAPS technical studies
[21]	2011	Wireless architecture	Overview of HAPS for Terrestrial and satellite networks
[22]	2011	Channel model	Review of modeling systems for HAPS and satellites
[23]	2011	Wireless architecture and communication links	Basic principles of HAPS systems and the use of HAPS for broadband communications
[24]	2016	Project deployments	An overview of HAPS technology, including technological developments
[25] [5]	2019	Wireless architecture and communication links	Surveys on future applications and challenges of haps and their use in mmWave communications.
[26]	2020	Wireless architecture	Using HAPS for legacy technologies, 5G and 6G
[27]	2020	Wireless architecture	Examining HAPS systems in terms of technology and technological developments and examining these systems for upcoming challenges
[9]	2021	Wireless architecture	A review of HAPS technical studies
[28]	2023	HAPS antenna design	Special Vivaldi antenna design for HAPS coverage enhancement

2-1-Classification Of Wireless Communication Networks

Wireless telecommunication systems have rapidly developed their networking capability, enabling better and more advanced services for various wireless telecommunication applications. There are several methods of classifying wireless communication networks based on network usage, technology used, bandwidth, and frequency range. In terms of geographical coverage, telecommunication networks can be divided into three groups: personal networks, which cover a range of up to 1 meter; local networks, which cover a range of 10 meters to 1 km; and urban networks, which cover a range of 1 to 10 km[17,29-30].



2-1-1 W-PAN[1] Network

A personal network refers to a group of interconnected devices that communicate with each other using frequency waves. This network also allows connection to the local Internet network. The standard communication range for this type of network is 10 meters at a frequency of 2.4 GHz. The data rate for communication between devices can be increased to up to 55 megabits per second and may be either exclusive or peer-to-peer. Additionally, power consumption in such systems is low and the overall cost is relatively inexpensive. The most well-known standard used in this field is Bluetooth, which is also known as IEEE 802.15[31-33].

2-1-2 W-LAN[2] Network

The WLAN network is a communication network that connects personal computers within a limited area. This network allows computers to communicate with each other without the need for wires and enables efficient data transfer. The network works by connecting devices through access points, and it can cover an area of up to 100 meters. The popularity of WLAN technology in both home and commercial communication systems is due to its ease of use, high mobility, rapid expansion, and economic efficiency. The standard for this technology is known as IEEE 802.11, which uses the Ethernet protocol and multiple access. A common [31]application of this technology is WiFi, which operates in the frequency range of 2.4 to 5.8 GHz [34, 35].

2-1-3 W-MAN[3]Network

A W-MAN network is a type of network that covers a larger geographical area than a LAN. It includes communication between several buildings and can even connect an entire city. In some cases, a W-MAN network is a connection between several WLANs that interact with each other through an operation center. This network must be operated and controlled by an organization to connect the dedicated networks of several smaller organizations. The technology used for this type of network is known as IEEE 802.16, which operates in the frequency range of 2 to 11 GHz. WiMax is the brand name of this technology and is widely used today as a method of internet communication [31].

2-1-4 W-WAN[4] Network

[1] Personal Area Network (PAN)
[2] Local Area Network (LAN)
[3] Metropolitan Area Network (MAN)
[4] Wide Area Network (WAN)

This type of network can facilitate communication between moving objects on a local, national, or even global scale. Its cellular form provides high mobility, fast access to information, and overcomes physical limitations. Over the years, various standards have been introduced in this field, resulting in different generations of cellular communication. Today, mobile phones are available in the first, second, 2.5, third, fourth, fifth, and sixth generations [32].

3- High Altitude Platform System (HAPS)

3-1-An overview of HAPS

The HAPS telecommunication system uses high-altitude air bases to relay information for various purposes. This technology utilizes advances made in the field of microwave power transmission through solar power generation systems. Despite its simplicity, it has a high potential for applications, especially for providing cellular communication and broadband services in remote areas and ocean regions where it is not feasible to establish infrastructure at a reasonable cost. The system can operate continuously in the upper layers of the atmosphere for extended periods. Although telecommunication systems in the stratosphere layer are old, they are now being recognized as an efficient technology. Several organizations are promoting and developing HAPS-based telecommunication systems for wireless communications, as well as remote control and monitoring methods. HAPS systems operate at an altitude of more than 20 km due to the minimum wind speed in the stratosphere at this altitude. The figure below illustrates the relation between height and wind speed [36,37].

Table 2- Comparison of different telecommunication structures based on their location

	GEO	LEO	HAP	Terrestrial
Station Coverage (km)	Global	More than 500	up to 200	Less than 1
Cell Size (km)	MIN400	50	1-10	1-0.1
Service Area	Global	Global	Regional	Local
Maximum Data Transfer Rate for Each User (Mbps)	155	Spend less than 2	25-155	155
System Development	Flexible	Lots of satellites	Flexible	Several central stations
Start Of Service (Year)	1998	2005	2003-2008	2000

The signal delay at this altitude is much lower compared to satellite signals, resulting in minimal transmission delay. Typically, the HAPS system lasts for about 5 years, after which it lands on the ground to be refueled, renovated, upgraded, and prepared for a new mission. Figure 1 provides a comparison between the location of the HAPS system and other telecommunication systems [38].

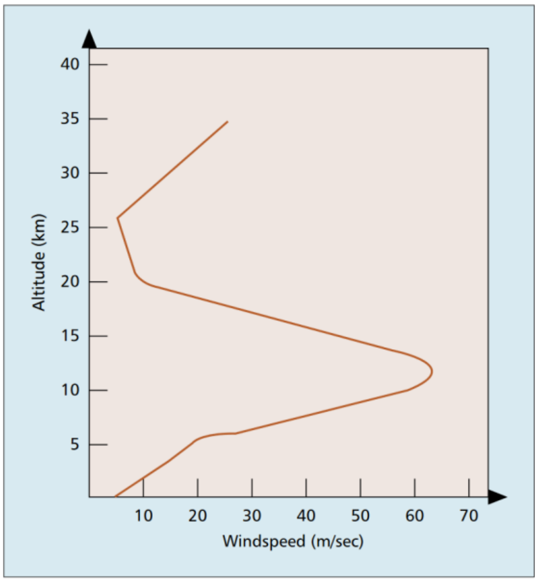


Figure 2-Wind velocity with respect to the altitude[16]

The signal delay is significantly less at this height compared to the satellite signal, which means that transmission delay will be minimal. Generally, the HAPS system has a lifespan of around 5 years, after which it lands on the ground to be refueled, renovated, upgraded, and prepared for a new mission. Figure 2 displays a comparison between the location of the HAPS system and other telecommunication system [26].

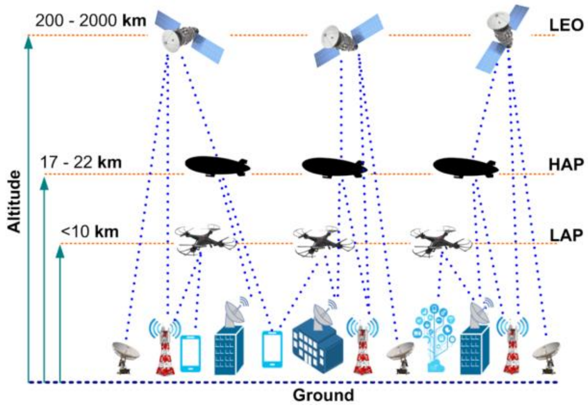


Figure2-Application of the HAPS system along with other telecommunication infrastructures at an altitude of 17 to 22 km [39]

3-2-Classification of the HAPS system

3-2-1 unmanned spacecraft

Unmanned spaceships can reach an altitude of up to 70,000 feet and remain there. They are over 100 meters in length and can carry loads weighing over 800 kg. Propulsion and electric power are used to keep the ship stable in the air. Due to the heavy liquid fuel, solar cells are utilized for producing electric power. These spaceships are constructed using lightweight materials and can be stationed in a fixed location for up to 5 years. Many countries currently use this type of device for wireless communication [40].

3-2-2- Unmanned aircraft

This type of aircraft is constructed using lightweight, high-tech materials, and is equipped with wide wings and electric motors that allow it to follow a programmed air path for extended periods. The US Space Agency has designed several of these aircraft, which are powered by solar cells located on their wings. While their flight duration varies from a few days to a month, it is theoretically possible for them to remain airborne for up to six months, and research is ongoing to achieve this. Compared to spaceships, these aircraft have the advantage of higher speed and maneuverability, and their smaller size makes flight preparation and maintenance easier [41, 42] .

3-2-3- Airplane with passengers

This device is a piloted aircraft that is specially designed to fly at high altitudes. Due to fuel and manpower limitations, the duration of the flight is typically a few hours. This type of aircraft is commonly used for military and meteorological purposes [43-45].

Table 3- Comparison of characteristics of vehicles used as HAPS structure

parameters	Passenger plane	Unmanned aircraft	Unmanned spaceship
Size	About 30 meters	Wingspan 35 to 70 meters	150 To 200Meters
total weight	2.5tons	1tons	30tons
flight length	Fossil Fuels	Solar Cells	Solar Cells
energy source	4to 8 hours	About 6 months	Up to 5 years
radius of motion	About 4 km	1to 3 km	Up to 1 km in three dimensions
load carrying capacity	up to 200 kg	50to 300 kg	1to 2 tons
Required motor power	40kW	3 kW	10 kW

The movement of flight structures in high-altitude systems is a critical issue. While an airplane has to fly in a relatively small circle, with a radius of up to 2 km, a spaceship can remain stationary in the air with only the kinetic force required to resist the wind. The International Telecommunication Union has established the range of motion for the HAPS system to be around 400 meters. Although it is easier for a spaceship to remain in the air than an airplane, it is more difficult to control and steer due to wind and air pressure changes[31,45].

3-3- HAPS system components

A high-altitude system is made up of ground and air sections. Figure 4 displays the main structure and the ground communication section[46,47].

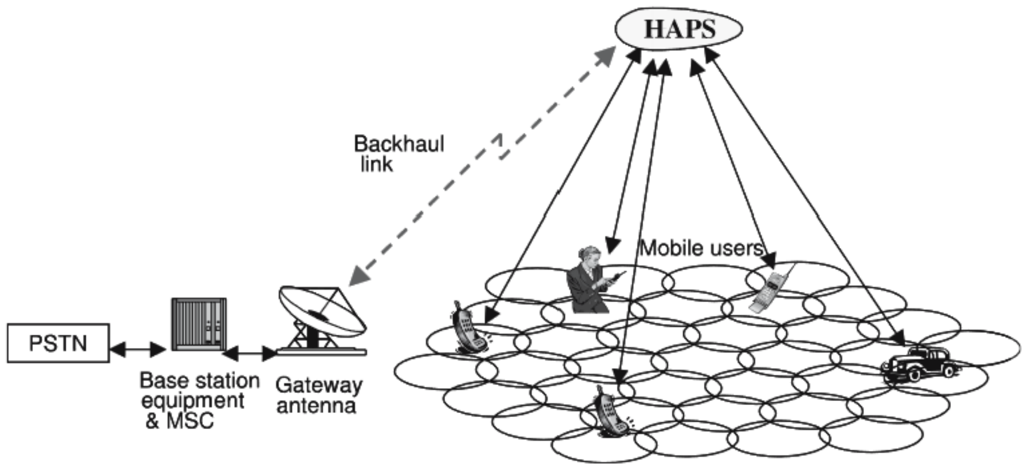


Figure 4- HAPS system components [17]

In the previous sections, we learned about the information relay section which is a flying object that comes in three different forms: a manned plane, an unmanned plane, or a spaceship. This object maintains its position in the air relative to the ground station by using special technologies to control the air currents. It is important to note that since this system does not leave the atmosphere, it must comply with international aerospace laws [48]. If the flying object is a spacecraft-type, then it is usually filled with helium gas in a balloon-like structure. The size of the balloon depends on the weight of the equipment it carries and the altitude at which the spacecraft must remain stable. The surface of the balloon is covered with solar cells which provide all the necessary energy for its different parts. These parts include engines that keep the ship in the air, telecommunication parts, and solar cell chargers[49,50].

The energy source is a crucial aspect of the HAPS system. Fossil fuel is not practical due to its high weight. The ideal fuel source is solar energy since these systems are located at high altitudes with wide surfaces that can easily be covered with solar cells. However, the problem is in storing this energy for use during the night [51].

The technology used for continuous energy production in spaceships is regenerative fuel cells. These cells weigh much less than conventional batteries and can provide the necessary energy day and night. During the day, the cells combine hydrogen and oxygen through chemical reactions to produce electrical energy and water. Oxygen and hydrogen are obtained from water during the electrolysis process and are stored to produce energy at night [52,53]. The High Altitude Platform Station (HAPS) system includes a telecommunication component consisting of a multi-beam or fuzzy antenna array, communication link antennas, and numerous processors responsible for receiving, multiplexing, switching between routes, and sending signals. The HAPS system uses multiple access methods such as CDMA and TDMA, and can function as a separate station in a network structure or as a part of a ground or satellite system [27,54,55].

The antenna is a vital element of the HAPS system. The signal is typically sent to ground stations in a cellular pattern, making the system susceptible to inter-channel interference. Therefore, it is essential to design an antenna with high-performance characteristics for proper frequency separation and high spectral efficiency [56]. Since the HAPS system operates simultaneously with satellite and terrestrial systems, there is a possibility of frequency interference in the same bands, necessitating the design of a precise antenna to prevent out-of-band radiation [57].

HAPS systems need to work in harmony with other telecommunication systems and to do this, the ITU has established a reference radiation pattern for CDMA-based HAPS system antennas in the IMT-2000 band. This is achieved using a phased array antenna with digital beam-forming technology that produces multiple beams with high performance [58].

Currently, many countries are researching the development of multi-beam antennas for HAPS systems. Japan and South Korea have presented preliminary plans for this system. Two types of multi-beam antennas can be used for a HAPS system, depending on the frequency band. For millimeter wave bands (47/48 GHz or 20/30 GHz), both multi-valve and multi-beam antennas can be used, while for lower frequencies such as S-band, multi-beam antennas are more effective. Important factors to consider when designing HAPS system antennas include operating frequency, sideband radiation, regional coverage, data transmission and reception capacity, and the stability and reliability of the system [16,59,60].

One of the crucial parts of a high-altitude system is its ground component, which receives multiple signals in the form of cellular patterns. The array antennas determine the coverage area and viewing angle of each beam, based on the capacity requirement of the entire system in each region. The power allocated to each cell is controlled to maximize the system capacity, with larger cells used in low-density areas and smaller cells in high-density areas [61]. A HAPS system can offer mobile multiple coverage or fixed wireless services in various regions, from high-density cities to low-density rural areas. Beamforming or antenna array technology can be used to cover the surface of the earth. [23, 56,62]The HAPS system is connected to other telecommunication infrastructures via the ground station, serving as a part of the entire telecommunication system of a region. For instance, communication with the HAPS system is possible through mobile phone devices via hub stations between the HAPS system and the mobile phone infrastructure. Additionally, international roaming services can increase the reach of this type of communication. [57- 61]

3-4 -Allocation of frequency spectrum for HAPS system

The ITU organization has specifically reserved 600 MHz bandwidth at 47.48 GHz for the services provided by HAPS systems. Of course, this spectrum is in the global dimension, which is also shared with the use of satellites. For the Asian continent, this spectrum is also defined at 28.31 GHz. The HAPS system can be used on the third generation and has an approximate frequency of 2 GHz. It is also possible to use the 18 to 32 GHz band for the use of fixed location services. The 28/31 band is more suitable than the higher 48/47 band because the upper band is very vulnerable to attenuation caused by rain, which is very acute in tropical regions [62].

Table 4- shows the frequency bands assigned to the HAPS system [63-65]

Frequency band	Shareable services	Services provided	Link direction	Area covered
47.9-48.2 GHZ 47.2-47.5 GHZ	Fixed and mobile services, satellite transmission, radio astronautics	Fixed	Send and Recieve	Global
31.0-31.3 GHZ	Fixed and mobile services, space sciences	Fixed	Send	40 countries in the world
27.5-28.3 GHZ	Fixed and mobile services, satellite transmission	Fixed	Receive	40 countries in the world
1885-1982 MHZ 2010-2025 MHZ 2110-2170 MHZ	fixed and mobile services (especially land IMT-2000 and PCS)	IMT-2000	Send and Recieve	District 1 and District 3

4- Capacity and channel model in the HAPS system

Channel capacity is a crucial design parameter for any telecommunication system. It is calculated based on Shannon's law and depends on the signal-to-noise ratio. However, in the HAPS system, two other types of interference affect the capacity: inter-cell interference and intra-cell interference. Inter-cell interference is caused by signals from neighboring cells, while intra-cell interference is caused by different antenna configurations within the same cell. One potential solution to compensate for inter-cell interference is to control the power sent to users based on their location. The use of millimeter wave bands has shown improved frequency efficiency in the HAPS system. However, the efficiency is not comparable to that of terrestrial cellular systems due to the limitation of the minimum cell size in the HAPS system, which is caused by the maximum size of the antenna. Figure 5 illustrates the bandwidth of the HAPS system at a fixed data rate and for different signal-to-noise ratios[28, 66]

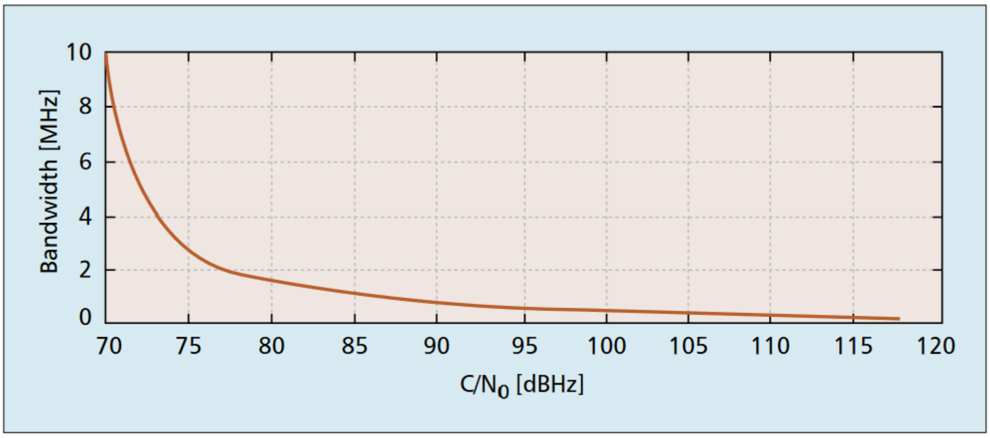


Figure 5- Minimum bandwidth at a data rate of 10 Mbps for different C/N ratios [16]

In designing a telecommunication system, the channel model, or the way signal propagation in the communication environment is modeled, is crucial. In the HAPS system, fading is always present when there is no direct line of sight. Even in direct line of sight, a small amount of fading may occur due to reflection from different surfaces. If the receiver is stationary, variations in the received power occur due to the relative motion of various factors that cause signal fading. Therefore, the receiver adds different signals with different gains and delays together, which can either constructively or destructively interfere. [56] [67, 68]

The satellite communication channel follows the law of free space propagation, where the received power delay is a function of the square of the distance between the transmitter and the receiver. The HAPS channel is similar to the satellite system in many ways, although the signal loss along its path is much less. Low-scale fading usually has a Rician distribution, although in some cases, the Rayleigh distribution is assumed for urban areas. Compared to terrestrial systems, the HAPS system has better emission properties [27, 51, 53].

In the earth station channel model, the power delay is a function of the fourth power of the distance between the transmitter and the receiver. In low-scale fading, the Rayleigh model is usually considered. In the same conditions, the extinction model in the HAPS system is Rician, and its propagation model is similar to the satellite system [21] [60].

When it comes to channel modeling, it's important to consider the impact of rain-induced attenuation. While this kind of attenuation is not too significant in the 2 GHz frequency band, it becomes very noticeable at higher frequencies (20 GHz). Raindrops can cause the signal to break and change its path, which results in a reduction of transmission power due to their energy absorption. The figure below illustrates the attenuation caused by rain, fog, water vapor, and oxygen in different frequencies [31, 47, 50].

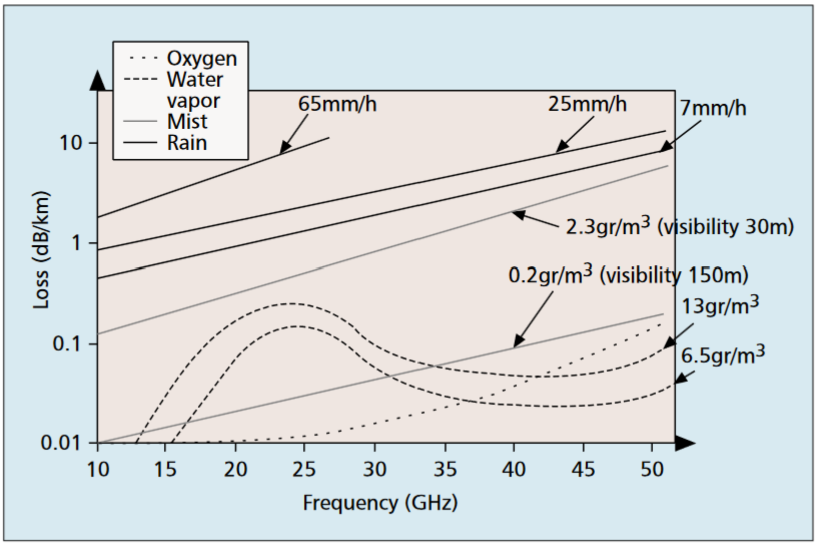


Figure 6 – Attenuation caused by different factors as a function of frequency [17]

The investigations carried out in the HAPS system at 28 GHz frequency have revealed that rain is the main cause of signal weakening. To address this issue, various multiple access methods based on user categories and traffic in each area have been researched and can be used .Another crucial issue in any telecommunication channel is interference. In the HAPS system, interference is caused by the overlap of the main and secondary lobes of the antenna. There are two types of interference: interference from HAPS system users, and interference caused by shared bands with terrestrial and satellite systems . The form of interference differs between the HAPS system and the ground model. In the ground model, the amount of interference is limited, but it is challenging to predict due to the complex structure of the ground and existing obstacles. In contrast, predicting interference in the HAPS system is easier, as the release in free space allows for more accurate predictions[25, 44, 69] .The two standards, DVB-T and DVB-H, which are used to send and receive multimedia on the ground, depend on the structure of the coverage area for proper operation. To cover the central areas, higher or more ground stations are used. A high-altitude telecommunication system can come in handy for ground stations in such places. This system acts as a repeater or transmitter in the DVB/DAB structure. Such stations based in the sky consume less power than ground types, for example, a tower-based in the sky of the HAPS type requires 1 watts of power to serve HDTV, while in the same application, a ground station requires 1000 watts of power [70-72].

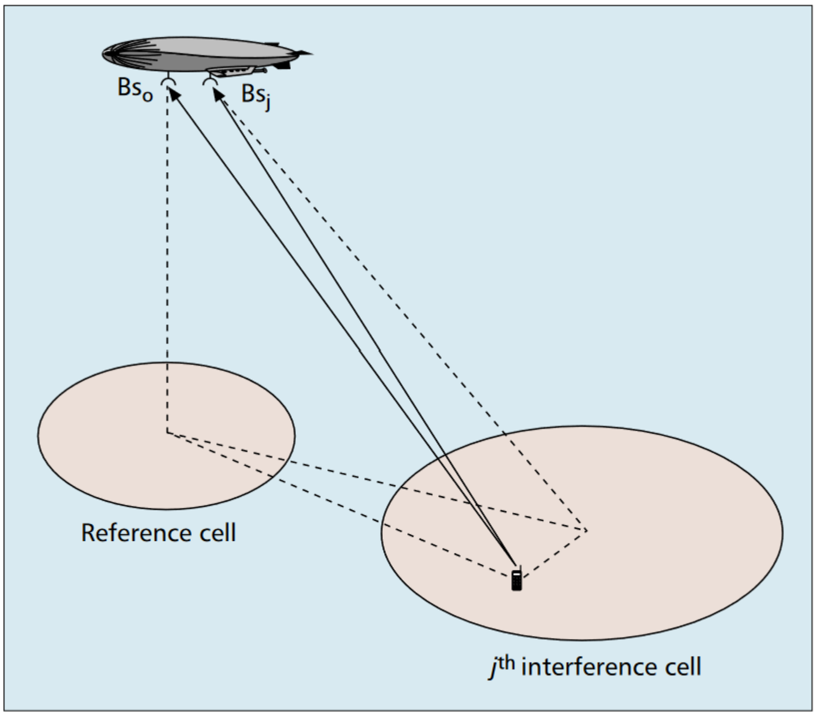


Figure 7- Signal interference geometry in HAPS transmission link [17]

The cell of reference can be found beneath the aerial structure and is supported by the BS0 station. A mobile station is situated in the jam cell and besides its link, it also has an interfering link to the reference cell. Studies have shown that interference from each cell's four lateral neighbors is typically the most impactful [42].

4-1-Data transmission and coding methods

The efficient transmission of data through a telecommunication system and the application of coding to improve its performance are crucial. The HeliNet project has investigated the optimal modulation method in various techniques like QPSK, QAM, M-APSK, CPM, GSMK, and MA-MSK. The project has also studied different error correction coding methods based on signal delay, error rate, and cost. The coding methods that were investigated include convolutional, turbo, multiplicative, and RS coding methods. Coherent demodulation methods prove useful in the absence of severe fading, and using a signal equalizer in low emission angles can improve the system. To increase the flight system's efficiency and consume less power, adaptive modulation methods have been implemented. Higher-order modulations are used in clear weather conditions, which help with the link budget calculations alongside the coding methods. The research aims to find an optimal model for combining the modulation/coding method under varying signal attenuation conditions. A suitable approach is to use adaptive modulation and coding techniques. Due to the HAPS system's centralized structure, the flight system's station can determine the optimal modulation/coding model based on each user's channel loss [25, 42, 44, 69].

Finally, the HAPS system has various applications, including but not limited to: [40]

5-Applications of HAPS system

The HAPS system has technical indicators that make it ideal for use in various applications. By integrating sending and receiving links to the user, along with supporting links such as optical fiber, the HAPS system can be used for telecommunication services. Furthermore, the use of inter-system links can create a network of HAPS systems, wherein the direct link between HAPS and satellite is also used simultaneously[38, 73, 74].

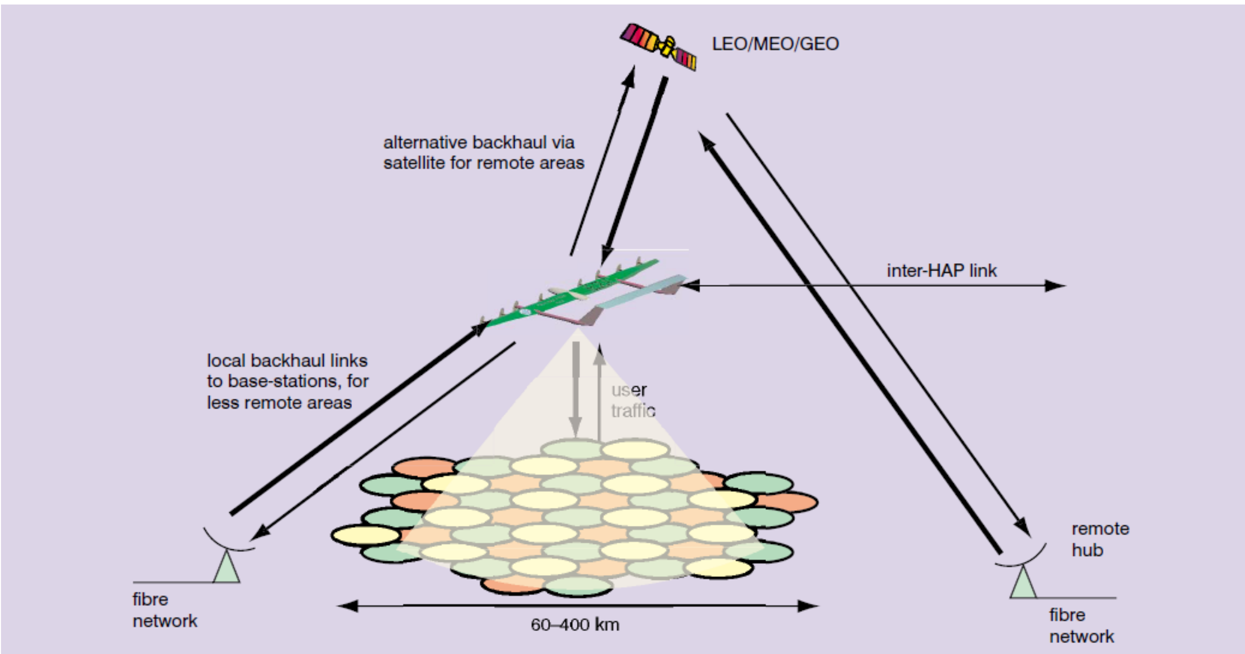


Figure 8- HAPS telecommunication structure

Compared to ground-based communication systems, High Altitude Platforms (HAPS) have a much higher coverage power. A single HAPS system can perform as well as multiple central ground stations. Moreover, obstacles that would normally be problematic for ground-based systems are not a limitation for HAPS. In the following, some important applications of the HAPS system will be briefly mentioned [75,76].

5-1-Advantages of using the HAPS system

Telecommunication systems located at high altitudes have advantages that are mostly due to their location. Some of these benefits are mentioned below [13].

***The extent of the covered area:**

The geometry of HAPS has been designed in such a way that the long-range links experience less attenuation due to rain compared to terrestrial links. This is because the links pass through a shorter path in the atmosphere. This advantage is particularly noticeable in high frequencies, also known as millimeter waves, which allow for a better link budget to cover wide areas [17,19] .

****Low cost:**

A group of HAPS systems has significantly lower setup and maintenance costs compared to a GEO or LEO satellite system. Additionally, a network based on HAPS can be developed at a lower cost than a terrestrial cellular system that requires a large number of stations. For instance, there will be no expenses related to land acquisition, environmental impacts, installation and operation, and electrical energy [2, 5, 9, 77].

*****Ability to develop at high speed:**

The HAPS system enables the service to commence with a small and simple structure that can expand rapidly to cover wider areas in the future. This is in contrast to the development process of the LEO satellite system, which necessitates a large number of separate satellites to achieve complete coverage. To begin the entire system, a significant number of ground stations are required for in-ground systems [2, 5, 9, 77].

5-2- Some active HAPS projects

Numerous research projects have been conducted worldwide regarding high-altitude wireless communication technology. These projects have been carried out in various countries including the United States, Japan, and the European Union. Some of the projects include SkyStation, HALO, SkyTower, Satellite, SkyNet, and HeliNet. Below is a brief overview of these projects including their specifications and operating methods [43].

SkyNet in Japan

The National SkyNet project was a wireless telecommunication initiative implemented by the National Science and Technology Administration of Japan and the Ministry of Communications and Posts. It involved using a balloon located at an approximate height of 20 kilometers to carry the required equipment for telecommunications and environmental control. The system comprised multiple balloons and fixed and mobile receiving equipment on the ground. Each flight structure covered a radius of 100 km and the section under its coverage was divided into smaller sections with a radius [69].

Helinet in Europe

The Helinet project is a three-year initiative that aims to implement a high-bandwidth wireless communication system using the HAPS system. The project will analyze the system from various aspects. The flying structure of an airplane with a wingspan of approximately 70 meters is capable of flying in a circular path at a height of 17 to 20 kilometers, or even remaining stationary. The aircraft can move up to 4 km in the horizontal direction and up to 1.5 km in the vertical direction. [53]

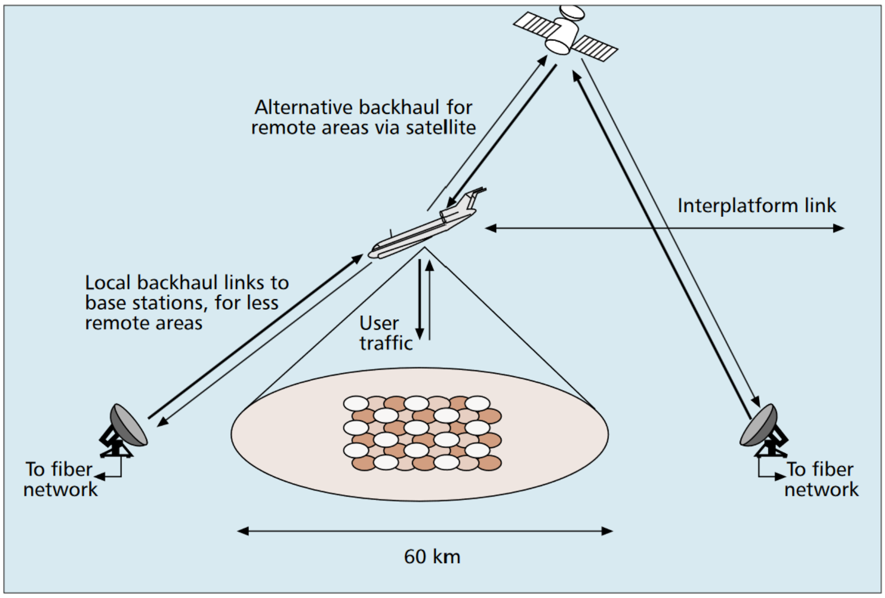


Figure 9- HeliNet project architecture [16]

Current research is being conducted in the field of millimeter wave transmission and propagation. The system's ability to support a large number of cells, antenna design, investigation of inter-signal interference, and the impact of rain and atmospheric absorption on signals are also being examined[16].

6-Architecture of HAPS telecommunication systems

6-1- Network design containing HAPS system

A HAPS system is designed to offer high reliability, low power consumption, and low equipment weight. This design approach puts most of the system's complexity in the ground part. In essence, the HAPS system acts as a telecommunications relay between the transmission link and the reception. The system itself also acts as a processor, performing complex operations such as information multiplexing, antenna beam shaping, and telecommunications signal processing. According to the International Telecommunication Union (ITU), each independent HAPS system covers an area with a radius of 150 km. For instance, in Japan, a system comprising 16 independent units provides nationwide coverage. The figure below illustrates the relationship between the maximum radius of the area covered by the HAPS system and its altitude [38].

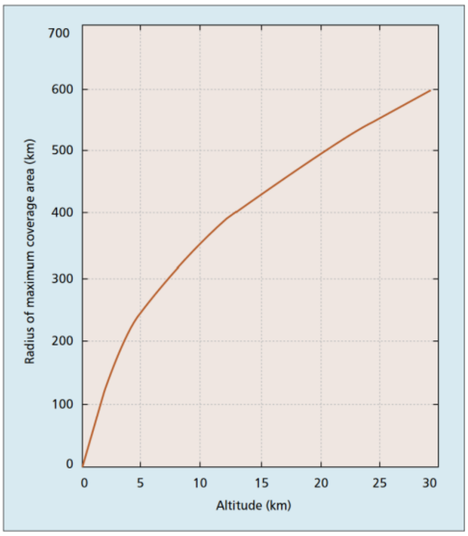


Figure 7- The radius of the maximum covered area as a function of the height of the HAPS system [16]

The size of the vertical viewing angle has an impact on the coverage area and the risk of radiation loss or signal interruption in the border areas. For broadband wireless communication, an angle of 5 degrees is optimal, but a 15-degree angle is commonly used to avoid signal interruption on the earth's surface. This means that a system placed at an altitude of 20 km can provide coverage to a radius of 200 km. To connect the sky-based system to other ground infrastructures, the ground system can be located on the roof of a building. In remote areas without access to ground infrastructure, a satellite network is used for connection. For communication between HAPS systems in the sky, an optical link is one option that uses compact wavelength multiplexing technology. Although optical technology facilitates high-speed data transmission, targeting, and interception remain significant challenges. In this context, the FLEXTEC method has been introduced as the optimal solution[78]

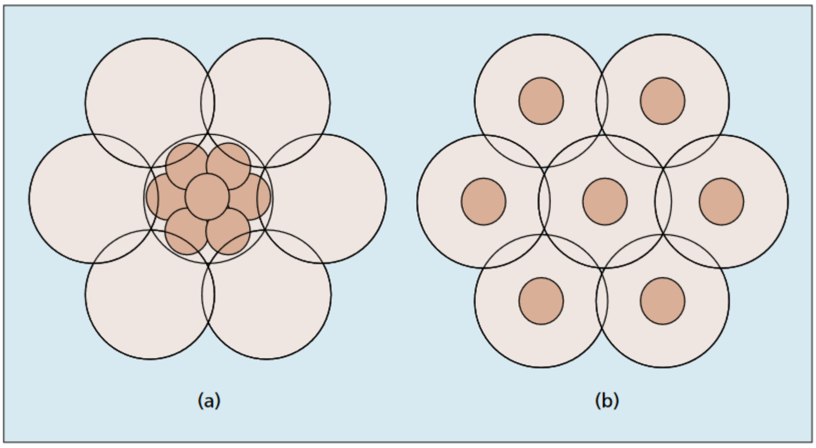


Figure 8- Formation of cells based on area traffic, microcell structure in a and microcell in b [16]

In cellular networks, one way to improve the system's performance is to divide each cell into separate parts. This can be achieved by placing the cell centrally within a circle and dividing the surrounding rings into separate parts. An illustration of this division method is shown in the figure9 [17].

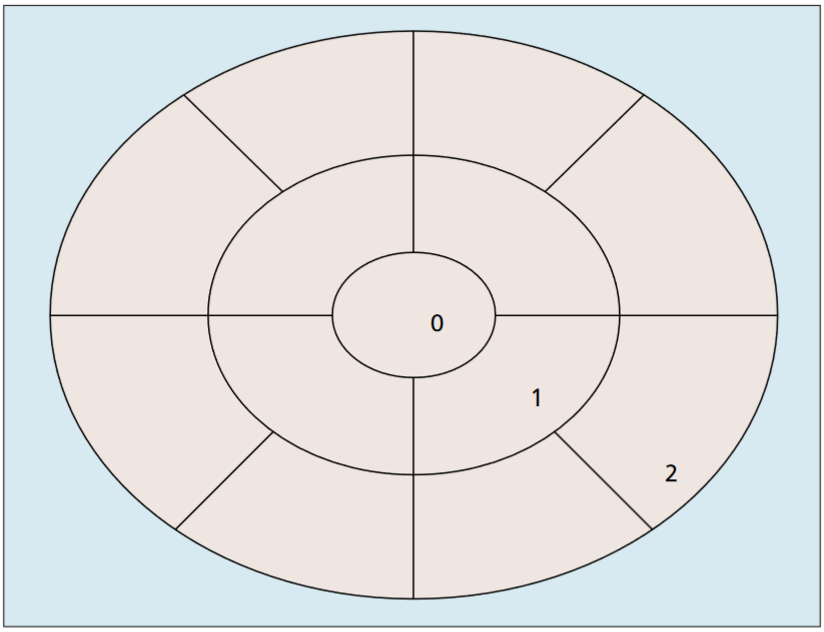


Figure 9- Cell division with two outer circles [17]

6-2 Different HAPS system architectures

In general, three types of architecture for high-altitude telecommunication systems can be imagined based on their network infrastructure, each of which will be briefly reviewed below. [20]

6-2-1 HAPS system as an independent structure

The high-altitude system can function as an independent system in many applications. The structure of this system is shown in Figure 10[7] HAPS system architecture can be very diverse and open. In the previous examples, the main goal was to provide telecommunication services with high bandwidth and sending and receiving from fixed and mobile users on the surface of the earth. Although the HAPS system can provide service in various and new applications that may be impossible in the first place. An example is weather balloons based on the HAPS system.

The United States Space Agency has developed high-altitude weather balloons to cover rural areas. As you know, rural areas in the United States make up 90% of the land of this country. Therefore, equipping this area with low-density telecommunication towers is not very economical.

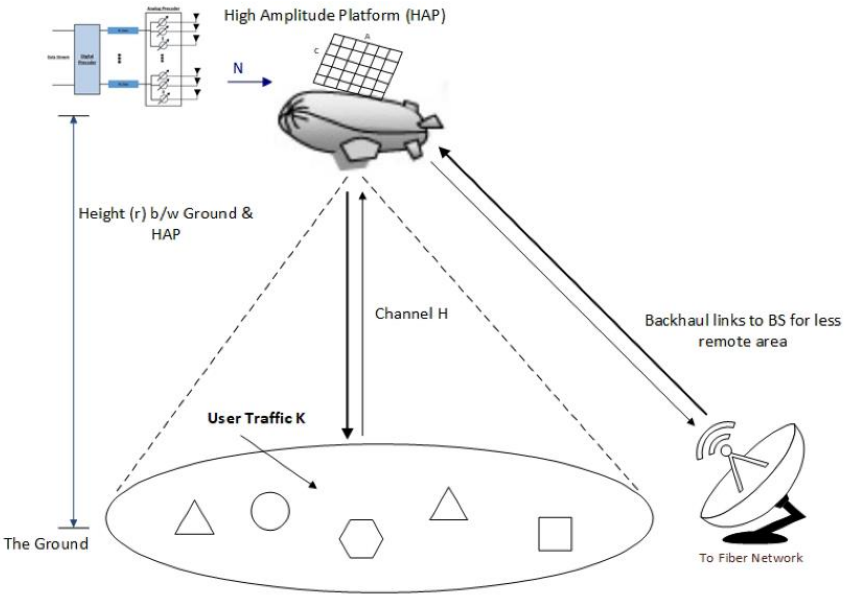


Figure 10 - HAPS system independently [79]

In rural and remote areas, setting up and using terrestrial telecommunication systems is not very cost-effective. In addition, it is not logical to set up a satellite system in a situation where the traffic demand is small. In such a situation, a high-altitude system can economically and effectively meet the needs of the region. A backup link can establish the necessary connection with the size of the infrastructure through the fiber network or satellite .[41]

6-2-2 -Ground HAPS system

As mentioned earlier, 6G has also been proposed by the ITU as a platform for providing sixth-generation mobile phone services. This system is very competitive in terms of setup cost compared to terrestrial cellular systems and can cover a large number of telecommunication cells alone and support many users with a low data rate. The following figure shows the structure of this architecture: [28]

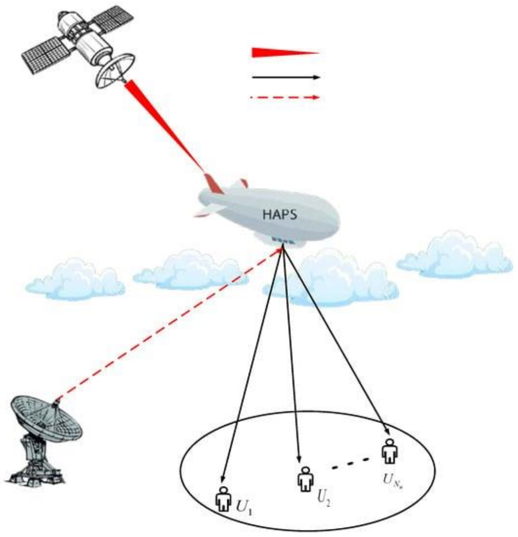


Figure 11- Ground-type HAPS system [80]

The wireless sensor network is also one of the other infrastructures that have been proposed for integration with the HAPS system. Considering the location of sensor networks in remote and inaccessible environments, the advantage of setting up and operating systems at high altitudes compared to similar cases based on ground stations is quite evident. An integrated HAP-WSN structure is shown in Figure 12, where the HAP system is used as a mobile gateway to compensate for multiple handovers between ground stations and a suitable replacement for ground gateways. [74]

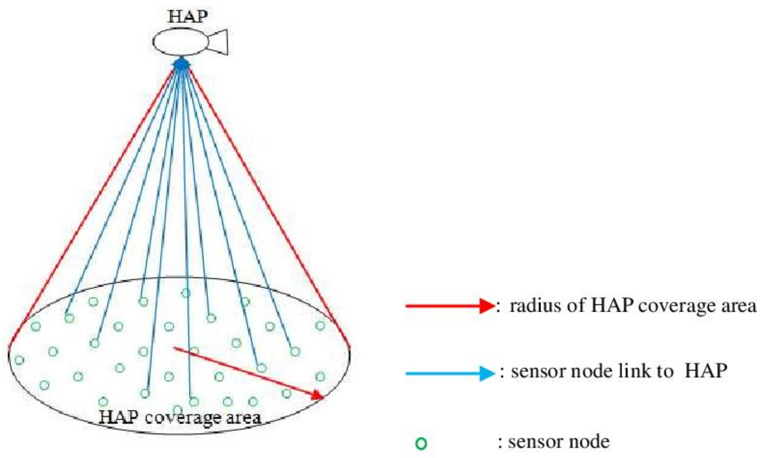


Figure 12- HAP-WSN system [81]

6-2-3 HAPS triple system, satellite, and ground

The triple network architecture based on HAPS, satellite, and ground system is shown in the figure13[44]

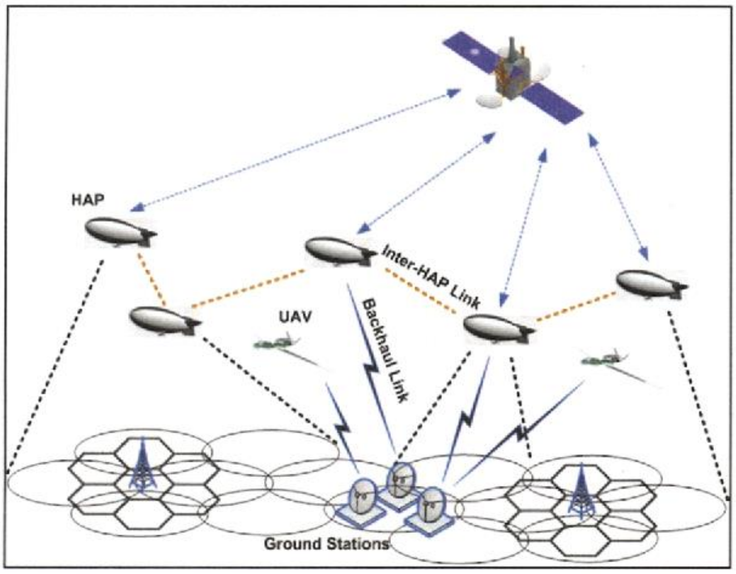


Figure 13- Integrated HAPS-satellite-ground station system [82]

This system consists of a communication link between the high-altitude system, the satellite, and the ground station. The most important indicator of this architecture is having the advantages of HAPS and satellite structures at the same time. First, the satellite's ability to broadcast globally and broadcast the multiple signals received from the fiber links to the HAPS system in the lower part is used [28].

7-Research in the future

Many technologies are introduced every day, whose purpose is to promote the increasing need for faster data transfer and high capacity for information communication. Among these, DSL, 3G, WLAN, and satellite communication technologies are widely used and are developing and improving every day. However, providing a service with a wide bandwidth and minimum propagation delay has been one of the important goals of telecommunication designers and engineers. Meanwhile, the high-altitude system, HAPS, can realize the said goal .To compare in terms of the development of HAPS system applications, it can be compared with satellite communication in the 1960s, and currently, only a few practical examples have been implemented. Researchers hope that in the coming years, some of the completed projects will come to fruition and prove the usefulness of this system, and after that, the first network based on the high altitude system will be formed [22,26,42].

In addition to the above, extensive research continues to improve the components of the HAPS system, which includes such things as the design of flight and ground station antennas, communication channel modeling, HAPS network hybrid architectures, and flight structures with greater flight length and higher maneuverability. Reducing power consumption and increasing data transmission capacity and other important parts of this system [40].

Reference

[1] A. Aragon-Zavala, J. L. Cuevas-Ruíz, and J. A. Delgado-Penín, *High-altitude platforms for wireless communications*. John Wiley & Sons, 2008.

[2] O. B. Yahia, E. Erdogan, and G. K. Kurt, "On the use of HAPS to increase secrecy performance in satellite networks," in *2021 IEEE International Conference on Communications Workshops (ICC Workshops)*, 2021: IEEE, pp. 1-6.

[3] b. T. C. T. a. D. Grace, "H igh-altitude platforms for wirelesscommunication," *ELECIKONICS & COMMUNICATION ENGINEERING JOIJKNAL,* 2001.

[4] S. H. Alsamhi and N. Rajput, "An intelligent HAP for broadband wireless communications: developments, QoS and applications," *International Journal of Electronics and Electrical Engineering,* vol. 3, no. 2, pp. 134-143, 2015.

[5] L. Zhang *et al.*, "A survey on 5G millimeter wave communications for UAV-assisted wireless networks," *IEEE Access,* vol. 7, pp. 117460-117504, 2019.

[6] L. F. Abdulrazak, T. A. Rahman, S. A. Rahim, and M. Yousif, "Study HAPS interference power to noise level ratio of fixed services and related separation distance," in *10th International Conference on Information Science, Signal Processing and their Applications (ISSPA 2010)*, 2010: IEEE, pp. 690-693.

[7] A. A. Abu-Arabia and R. Hakimi, "Performance of 5G services deployed via HAPS system," in *2019 IEEE 13th International Conference on Telecommunication Systems, Services, and Applications (TSSA)*, 2019: IEEE, pp. 168-172.

[8] S. Alfattani, A. Yadav, H. Yanikomeroglu, and A. Yongaçoglu, "Beyond-cell communications via HAPS-RIS," in *2022 IEEE Globecom Workshops (GC Wkshps)*, 2022: IEEE, pp. 1383-1388.

[9] Y. Xing, F. Hsieh, A. Ghosh, and T. S. Rappaport, "High altitude platform stations (HAPS): Architecture and system performance," in *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring)*, 2021: IEEE, pp. 1-6.

[10] T. Celcer, A. Svigelj, and M. Mohorcic, "Network architectures exploiting multiple HAP constellations for load balancing," *WSEAS Trans. Commun,* vol. 7, no. 3, pp. 160-169, 2008.

[11] I. Alocci, M. Berioli, N. Celandroni, G. Giambene, and S. Karapantazis, "Proposal of a reliable multicast protocol in a HAP-satellite architecture," in *2007 IEEE 65th Vehicular Technology Conference-VTC2007-Spring*, 2007: IEEE, pp. 1380-1384.

[12] R. Alghamdi, H. Dahrouj, T. Y. Al-Naffouri, and M.-S. Alouini, "Equitable 6G Access Service via Cloud-Enabled HAPS for Optimizing Hybrid Air-Ground Networks," *IEEE Transactions on Communications,* 2024.

[13] T. Tsujii, M. Harigae, and K. Okano, "A new positioning/navigation system based on Pseudolites installed on high altitude platforms systems (HAPS)," in *Proc. 24th Int. Congr. Aeronaut. Sci.(ICAS)*, 2004, pp. 1-10.

[14] G. Araniti, A. Iera, and A. Molinaro, "The role of HAPs in supporting multimedia broadcast and multicast services in terrestrial-satellite integrated systems," *Wireless Personal Communications,* vol. 32, pp. 195-213, 2005.

[15] !!! INVALID CITATION !!! [15-17].

[16] S. Karapantazis and F. Pavlidou, "Broadband communications via high-altitude platforms: A survey," *IEEE Communications Surveys & Tutorials,* vol. 7, no. 1, pp. 2-31, 2005.

[17] A. K. Widiawan and R. Tafazolli, "High altitude platform station (HAPS): A review of new infrastructure development for future wireless communications," *Wireless Personal Communications,* vol. 42, pp. 387-404, 2007.

[18] J. Gavan, S. Tapuchi, and D. Grace, "Concepts and main applications of high-altitude-platform radio relays," *URSI Radio Science Bulletin,* vol. 2009, no. 330, pp. 20-31, 2009.

[19] F. Fidler, M. Knapek, J. Horwath, and W. R. Leeb, "Optical communications for high-altitude platforms," *IEEE Journal of selected topics in quantum electronics,* vol. 16, no. 5, pp. 1058-1070, 2010.

[20] P. Aubineau, S. Buonomo, W. Frank, and K. Hughes, "ITU's regulatory framework, technical studies in ITU-R, and future activities in relation to high-altitude-platform stations (HAPS)," *URSI Radio Science Bulletin,* vol. 2010, no. 333, pp. 67-74, 2010.

[21] A. Mohammed, A. Mehmood, F.-N. Pavlidou, and M. Mohorcic, "The role of high-altitude platforms (HAPs) in the global wireless connectivity," *Proceedings of the IEEE,* vol. 99, no. 11, pp. 1939-1953, 2011.

[22] P.-D. Arapoglou, E. T. Michailidis, A. D. Panagopoulos, A. G. Kanatas, and R. Prieto-Cerdeira, "The land mobile earth-space channel," *IEEE vehicular technology magazine,* vol. 6, no. 2, pp. 44-53, 2011.
[23] D. Grace and M. Mohorcic, *Broadband communications via high altitude platforms*. John Wiley & Sons, 2011.
[24] F. A. d'Oliveira, F. C. L. d. Melo, and T. C. Devezas, "High-altitude platforms—Present situation and technology trends," *Journal of Aerospace Technology and Management,* vol. 8, pp. 249-262, 2016.
[25] M. Mozaffari, W. Saad, M. Bennis, Y.-H. Nam, and M. Debbah, "A tutorial on UAVs for wireless networks: Applications, challenges, and open problems," *IEEE communications surveys & tutorials,* vol. 21, no. 3, pp. 2334-2360, 2019.
[26] S. C. Arum, D. Grace, and P. D. Mitchell, "A review of wireless communication using high-altitude platforms for extended coverage and capacity," *Computer Communications,* vol. 157, pp. 232-256, 2020.
[27] G. K. Kurt *et al.*, "A vision and framework for the high altitude platform station (HAPS) networks of the future," *IEEE Communications Surveys & Tutorials,* vol. 23, no. 2, pp. 729-779, 2021.
[28] A. A. Kılıç and F. A. Yapar, "Antipodal Vivaldi Antenna Design for 6G High Altitude Platform System (HAPS)," in *2023 31st Signal Processing and Communications Applications Conference (SIU)*, 2023: IEEE, pp. 1-4.
[29] J. D. Deaton, "High altitude platforms for disaster recovery: capabilities, strategies, and techniques for emergency telecommunications," *EURASIP Journal on wireless communications and networking,* vol. 2008, pp. 1-8, 2008.
[30] F. Dong, Y. He, X. Zhou, Q. Yao, and L. Liu, "Optimization and design of HAPs broadband communication networks," in *2015 5th International Conference on Information Science and Technology (ICIST)*, 2015: IEEE, pp. 154-159.
[31] A. F. Molisch, *Wireless communications*. John Wiley & Sons, 2012.
[32] M. Elmahallawy and T. Luo, "FedHAP: Fast federated learning for LEO constellations using collaborative HAPs," in *2022 14th International Conference on Wireless Communications and Signal Processing (WCSP)*, 2022: IEEE, pp. 888-893.
[33] E. Erdogan, O. B. Yahia, G. K. Kurt, and H. Yanikomeroglu, "Optical HAPS Eavesdropping in Vertical Heterogeneous Networks," *IEEE Open Journal of Vehicular Technology,* vol. 4, pp. 208-216, 2023.
[34] Z. Lou, B. E. Y. Belmekki, and M.-S. Alouini, "HAPS in the non-terrestrial network nexus: Prospective architectures and performance insights," *IEEE Wireless Communications,* vol. 30, no. 6, pp. 52-58, 2023.
[35] G. Meng, N. Spahich, R. Kenjale, G. Waksman, and J. W. St Geme III, "Crystal structure of the Haemophilus influenzae Hap adhesin reveals an intercellular oligomerization mechanism for bacterial aggregation," *The EMBO journal,* vol. 30, no. 18, pp. 3864-3874, 2011.
[36] P. Pace, G. Aloi, F. De Rango, E. Natalizio, A. Molinaro, and S. Marano, "An integrated Satellite-HAP-Terrestrial system architecture: resources allocation and traffic management issues," in *2004 IEEE 59th Vehicular Technology Conference. VTC 2004-Spring (IEEE Cat. No. 04CH37514)*, 2004, vol. 5: IEEE, pp. 2872-2875.
[37] C. E. Palazzi, C. Roseti, M. Luglio, M. Gerla, M. Sanadidi, and J. Stepanek, "Enhancing transport layer capability in haps–satellite integrated architecture," *Wireless Personal Communications,* vol. 32, pp. 339-356, 2005.
[38] S. Shoichi, K. Hoshino, and O. Yoshichika, "Basic evaluation of service link antenna for footprint fixation in HAPS system," in *2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall)*, 2020: IEEE, pp. 1-5.
[39] S.-R. Sabuj, M.-S. Alam, M. Haider, M.-A. Hossain, and A.-S.-K. Pathan, "Low Altitude Satellite Constellation for Futuristic Aerial-Ground Communications," *Computer Modeling in Engineering \& Sciences,* vol. 136, no. 2, pp. 1053--1089, 2023. [Online]. Available: http://www.techscience.com/CMES/v136n2/51585.
[40] H. Otay, K. Humadi, and G. K. Kurt, "Dark Side of HAPS Systems: Jamming Threats towards Satellites," *arXiv preprint arXiv:2310.02851,* 2023.
[41] P. T. Bell and J. M. Shine, "Subcortical contributions to large-scale network communication," *Neuroscience & Biobehavioral Reviews,* vol. 71, pp. 313-322, 2016.
[42] A. A. Osman *et al.*, "Quantum Leap in Intervention, Rectification of High Annulus Pressure (HAP) at Offshore Malaysia Using a Novel Annulus Intervention System-Operator Case Study," in *SPE/IADC Middle East Drilling Technology Conference and Exhibition*, 2023: SPE, p. D021S009R002.
[43] D. W. Bliss, K. W. Forsythe, and A. M. Chan, "MIMO wireless communication," *Lincoln Laboratory Journal,* vol. 15, no. 1, pp. 97-126, 2005.

[44] H. Omote, S. Kimura, H.-Y. Lin, and A. Sato, "HAPS propagation loss model for urban and suburban environments," in *2020 International Symposium on Antennas and Propagation (ISAP)*, 2021: IEEE, pp. 681-682.
[45] N. Boschetti, J. Slay, J. Plotnek, G. Karabulut Kurt, and G. Falco, "An Overview of High Altitude Platform Stations (HAPS) Systems, HAPS Vehicle Architecture, and HAPS Cybersecurity," *ASCEND 2023,* p. 4800, 2023.
[46] C. A. Britson *et al.*, "HAPS Curriculum & Instruction 2022 Laboratory Survey: Laboratory Activities and Learning Outcomes," *HAPS Educator,* vol. 27, no. 2, 2023.
[47] M. Mohorčič, A. Vilhar, M. Beriolli, A. D. M. Werner, and A. Donner, "Optical transport network based on a meshed HAP system with interplatform links," in *Proc. Advanced Satellite Mobile Systems (ASMS) Conference*, 2006, pp. 29-31.
[48] E. W. Cheng, H. Li, P. E. Love, and Z. Irani, "Network communication in the construction industry," *Corporate Communications: An International Journal,* vol. 6, no. 2, pp. 61-70, 2001.
[49] E. Cianca *et al.*, "Integrated satellite-HAP systems," *IEEE Communications Magazine,* vol. 43, no. 12, pp. supl. 33-supl. 39, 2005.
[50] A. Mohammed and Z. Yang, "Broadband communications and applications from high altitude platforms," *International Journal of Recent Trends in Engineering,* vol. 1, no. 3, p. 239, 2009.
[51] J. Liu, Y. Shi, Z. M. Fadlullah, and N. Kato, "Space-air-ground integrated network: A survey," *IEEE Communications Surveys & Tutorials,* vol. 20, no. 4, pp. 2714-2741, 2018.
[52] F. De Rango, M. Tropea, A. F. Santamaria, and S. Marano, "An enhanced QoS CBT multicast routing protocol based on Genetic Algorithm in a hybrid HAP–Satellite system," *Computer Communications,* vol. 30, no. 16, pp. 3126-3143, 2007.
[53] D. S. Lakew, A.-T. Tran, N.-N. Dao, and S. Cho, "Intelligent offloading and resource allocation in hap-assisted mec networks," in *2021 international conference on information and communication technology convergence (ICTC)*, 2021: IEEE, pp. 1582-1587.
[54] P. Di Vito, D. Fischer, M. Spada, R. Rinaldo, and L. Duquerroy, "HAPs operations and service provision in critical scenarios," in *2018 SpaceOps Conference*, 2018, p. 2504.
[55] F. Dong, H. Li, X. Gong, Q. Liu, and J. Wang, "Energy-efficient transmissions for remote wireless sensor networks: An integrated HAP/satellite architecture for emergency scenarios," *Sensors,* vol. 15, no. 9, pp. 22266-22290, 2015.
[56] F. Hsieh, F. Jardel, E. Visotsky, F. Vook, A. Ghosh, and B. Picha, "Uav-based multi-cell haps communication: System design and performance evaluation," in *GLOBECOM 2020-2020 IEEE Global Communications Conference*, 2020: IEEE, pp. 1-6.
[57] M. Islam and S. Jin, "An overview research on wireless communication network," *Networks,* vol. 5, no. 1, pp. 19-28, 2019.
[58] O. O. Khalifa, A. F. Ismail, M. R. Islam, and Z. E. O. Elshaikh, "High altitude platform for wireless communications and other services," in *2006 International Conference on Electrical and Computer Engineering*, 2006: IEEE, pp. 432-438.
[59] Z. Jia, M. Sheng, J. Li, D. Zhou, and Z. Han, "Joint HAP access and LEO satellite backhaul in 6G: Matching game-based approaches," *IEEE Journal on Selected Areas in Communications,* vol. 39, no. 4, pp. 1147-1159, 2020.
[60] A. Goldsmith, *Wireless communications*. Cambridge university press, 2005.
[61] W. Jiang, B. Han, M. A. Habibi, and H. D. Schotten, "The road towards 6G: A comprehensive survey," *IEEE Open Journal of the Communications Society,* vol. 2, pp. 334-366, 2021.
[62] S. Kandeepan, T. Rasheed, and S. Reisenfeld, "Energy efficient cooperative HAP-terrestrial communication systems," in *Personal Satellite Services: Third International ICST Conference, PSATS 2011, Malaga, Spain, February 17-18, 2011, Revised Selected Papers 3*, 2011: Springer, pp. 151-164.
[63] I.-R. Palma-Lazgare, J.-A. Delgado-Penin, and F. Perez-Fontan, "An advance in wireless broadband communications based on a WiMAX-HAPS architecture," in *26th international communications satellite systems conference (ICSSC)*, 2008.
[64] F. D. Rango, M. Tropea, and S. Marano, "Integrated services on high altitude platform: Receiver driven smart selection of HAP-geo satellite wireless access segment and performance evaluation," *International Journal of Wireless Information Networks,* vol. 13, pp. 77-94, 2006.
[65] Q. Ren, O. Abbasi, G. K. Kurt, H. Yanikomeroglu, and J. Chen, "Caching and computation offloading in high altitude platform station (HAPS) assisted intelligent transportation systems," *IEEE Transactions on Wireless Communications,* vol. 21, no. 11, pp. 9010-9024, 2022.

[66] Y.-J. Kim, S.-J. Ahn, P.-I. Hwang, G.-C. Pyo, and S.-I. Moon, "Coordinated control of a DG and voltage control devices using a dynamic programming algorithm," *IEEE Transactions on Power Systems,* vol. 28, no. 1, pp. 42-51, 2012.
[67] Z.-J. Ren, K. Chen, L.-D. Shou, G. Chen, Y.-J. Bei, and X.-Y. Li, "haps: Supporting effective and efficient full-text p2p search with peer dynamics," *Journal of Computer Science and Technology,* vol. 25, no. 3, pp. 482-498, 2010.
[68] L. Reynaud, S. Zaïmi, and Y. Gourhant, "Competitive assessments for HAP delivery of mobile services in emerging countries," in *2011 15th International Conference on Intelligence in Next Generation Networks*, 2011: IEEE, pp. 307-312.
[69] V. K. Nassa, "Wireless Communications: Past, Present and Future," *Dronacharya Research Journal,* vol. 50, 2011.
[70] A. A. Shamsabadi, A. Yadav, O. Abbasi, and H. Yanikomeroglu, "Handling interference in integrated HAPS-terrestrial networks through radio resource management," *IEEE Wireless Communications Letters,* vol. 11, no. 12, pp. 2585-2589, 2022.
[71] L. Song, B. Di, H. Zhang, and Z. Han, *Aerial Access Networks: Integration of UAVs, HAPs, and Satellites*. Cambridge University Press, 2023.
[72] S. Temel and İ. Bekmezci, "On the performance of flying ad hoc networks (FANETs) utilizing near space high altitude platforms (HAPs)," in *2013 6th International Conference on Recent Advances in Space Technologies (RAST)*, 2013: IEEE, pp. 461-465.
[73] Y. Shibata, N. Kanazawa, M. Konishi, K. Hoshino, Y. Ohta, and A. Nagate, "System design of gigabit HAPS mobile communications," *IEEE Access,* vol. 8, pp. 157995-158007, 2020.
[74] K. Tashiro, K. Hoshino, and A. Nagate, "Nullforming-based precoder for spectrum sharing between HAPS and terrestrial mobile networks," *IEEE Access,* vol. 10, pp. 55675-55693, 2022.
[75] T. C. Tozer and D. Grace, "High-altitude platforms for wireless communications," *Electronics & communication engineering journal,* vol. 13, no. 3, pp. 127-137, 2001.
[76] Y. Zhang, M. A. Kishk, and M.-S. Alouini, "HAP-enabled Communications in Rural Areas: When Diverse Services Meet Inadequate Communication Infrastructures," *IEEE Open Journal of the Communications Society,* 2023.
[77] S. Yuan, F. Hsieh, S. Rasool, E. Visotsky, M. Cudak, and A. Ghosh, "Interference analysis of HAPS coexistence on terrestrial mobile networks," in *2022 IEEE Wireless Communications and Networking Conference (WCNC)*, 2022: IEEE, pp. 2494-2499.
[78] T. Fujii, Y. Ohta, and T. Fujii, "A study on signal band division interference canceller for HAPS feeder links with multi-gateways," in *2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring)*, 2020: IEEE, pp. 1-7.
[79] S. u. Hassan, T. Mir, S. Alamri, N. A. Khan, and U. Mir, "Machine Learning-Inspired Hybrid Precoding for HAP Massive MIMO Systems with Limited RF Chains," *Electronics,* vol. 12, no. 4, p. 893, 2023. [Online]. Available: https://www.mdpi.com/2079-9292/12/4/893.
[80] K. O. Odeyemi and P. A. Owolawi, "A Mixed FSO/RF Integrated Satellite-High Altitude Platform Relaying Networks for Multiple Terrestrial Users with Presence of Eavesdropper: A Secrecy Performance," *Photonics,* vol. 9, no. 1, p. 32, 2022. [Online]. Available: https://www.mdpi.com/2304-6732/9/1/32.
[81] V. W. Mahyastuty, I. Iskandar, and H. Hendrawan, "Wireless Sensor Network Exploiting High Altitude Platform in 5G Network," *Buletin Pos dan Telekomunikasi: Media Komunikasi Ilmiah,* vol. 15, pp. 55-64, 2017.
[82] G. Avdikos, G. Papadakis, and N. Dimitriou, "Overview of the application of High Altitude Platform (HAP) systems in future telecommunication networks," *2008 10th International Workshop on Signal Processing for Space Communications,* pp. 1-6, 2008.