High Altitude Platform Systems

Towers in the Skies

June 2021

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Executive Summary

Operating in the stratosphere, unmanned high-altitude platforms (HAPS) could bring connectivity to areas that are either not covered, or are only partially covered, by terrestrial cellular networks.

This whitepaper highlights the potential of HAPS to meet the need for more broadband connectivity worldwide. HAPS are very versatile: they can be adjusted to prioritise coverage or capacity depending on the use case. Moreover, an aircraft can be deployed to cover a location at short notice. As HAPS can employ LTE and 5G, there are no special requirements on the user equipment: a normal smartphone can be used. As a result, HAPS can support a variety of use cases for both developed and developing markets, including:

- Greenfield coverage – providing coverage in areas with no cellular networks
- White spot reduction – filling in gaps in cellular coverage
- Emergency communications/disaster recovery – backing up damaged terrestrial networks
- The Internet of Things (IoT) – connecting sensors, appliances, machines and vehicles
- Temporary coverage for events/tourist hotspots – adding extra capacity in specific locations
- Fixed wireless access - a broadband alternative to deploying fixed lines
- Connectivity for urban air mobility and drones – providing better connectivity in the air
- Private networks - enabling organisations to deploy their own cellular connectivity
- Terrestrial site backhaul – connecting base stations and edge data centres to the Internet

HAPS implementation scenarios

For HAPS, the main implementation scenarios are likely to be:

- Dedicated: a mobile operator implements a HAPS platform for its own use.
- Shared: A HAPS platform may be deployed as a joint venture of participating mobile operators. This model allows the platform cost to be shared among operators.
- Neutral host: a private entity would deploy and operate the HAPS platform and offer it to operators in a "platform-as-a-service" model.
- Governmental: A government may deploy HAPS for civilian or military use.
- Hybrid: There will be cases that combine the aforementioned scenarios. For instance, a mobile operator may deploy HAPS, and as a host operator, it can offer the platform to other operators as a managed service.

HAPS technology

For HAPS, the key technological challenges to overcome include achieving a durable lightweight structure, energy storage and power delivery, thermal management, system reliability, navigation, endurance and safe operations at lower altitude. Different classes of HAPS may be more or less suitable for operation in different regions and for specific applications or use cases.

Balloons are small and lightweight, which simplifies some operational aspects. However, there is no means to accurately keep them positioned over a specific area and they have typically low power and cargo capabilities.

Fixed wing platforms can be positioned precisely and have larger weight, power and flight time capabilities than balloons. That enables the support of more complex applications. On average, cargos in the mid/high tens of kg and power above few hundred watts are achievable. They can also stay airborne longer than balloons, with flight times of several months in cases where the weight of the payload and power requirements are not large.

Airships are the largest platforms, with higher capabilities in terms of payload weight (several hundred kg), power (even above 10kW), and autonomy, which may reach up to a year. As with fixed wing solutions, they offer precise control of the positioning of the platform. However, the size of these systems introduces additional operational complexity.

Hybrid approaches mixing aerostatic and aerodynamic principles are under consideration and may lead to newer solutions with characteristics in-between those of airships and fixed-wing craft.

Regulation and spectrum for HAPS

Most civil aviation authorities define the regulated airspace as that below an altitude threshold of 60,000ft (FL600, 18.29 km). When an aircraft is operating above this altitude, it is no longer managed by traditional air traffic management (ATM) systems, which are also unable to manage and interact with unmanned aircraft.

The concept of space traffic management (STM) – to manage operations above 60,000ft - is in the explorative, discussion phase and it is not yet defined. But future regulations might cover STM and the required services, mandating certain on-board applications, such as identification and tracking.

Under ITU regulations, the only spectrum band where HAPS can currently act as a cellular base station is 2.1 GHz. However, WRC-23 agenda item 1.4 is looking to consider HAPS mobile services in certain frequency bands already identified for IMT: 694-960 MHz; 1710-1885 MHz and 2500-2690 MHz

Next steps

HAPs will need the support of an ecosystem, underpinned by partnerships and alliances (e.g. aerospace, telcos and government) and a new type of infrastructure providers - flying tower companies. The latter will need to have multidisciplinary competence, including aerospace and telecommunication know-how. To accelerate the development of HAPS, the following elements are also needed:

- Funding for R&D
- Adjustment of regulations on aviation and telecommunications

- Further studies on the use case scenarios and economics
- Additional concepts as to how to integrate HAPS into future network topology

To that end, the GSMA calling on telcos to help further study and consider HAPS opportunity into their future networks, while working with aerospace players to drive technical innovation in aircraft design and support systems to develop a sustainable carrier platform for telecoms payloads.

At the same time, governments and regulators need to recognise the importance of HAPS for achieving technological progress, accelerating the economy, and providing connectivity to their citizens. To that end, there is a need to develop an unmanned aircraft system and collaborative traffic management system in the stratosphere, while also meeting the increasing demand for suitable radio spectrum for HAPS.

Introduction

About this paper

Unmanned high-altitude platforms (HAPS) operating in the stratosphere are arousing increasing interest in research and industry. Among other applications, HAPS could provide major benefits for the telecommunication industry: they can complement terrestrial network operations by covering more surface area, are less prone to interference and can be deployed quickly[1].

HAPS are aircraft or balloons that fly or float at altitudes of about 20km. Unmanned, they operate autonomously, with some of the systems being able to remain on-station at a specific location. They can also take-off and land, making it possible to conduct periodic maintenance and changes to payloads. In addition to conventional applications, such as remote sensing or in-situ measurement for earth observation, HAPS enable operations in crisis areas or can serve as network nodes, for example[2].

The objective of this whitepaper is to promote the use of HAPS technology to meet the need for broadband connectivity worldwide. It is potentially suitable for rural areas, areas with no/low connectivity and inaccessible areas where it is difficult to build terrestrial towers.

This paper is written for those who have an interest in the development of HAPS and how they can deliver mobile broadband connectivity.

Acknowledgment

The white paper has been created thanks to the following contributing mobile operators:

And supporting mobile operators:

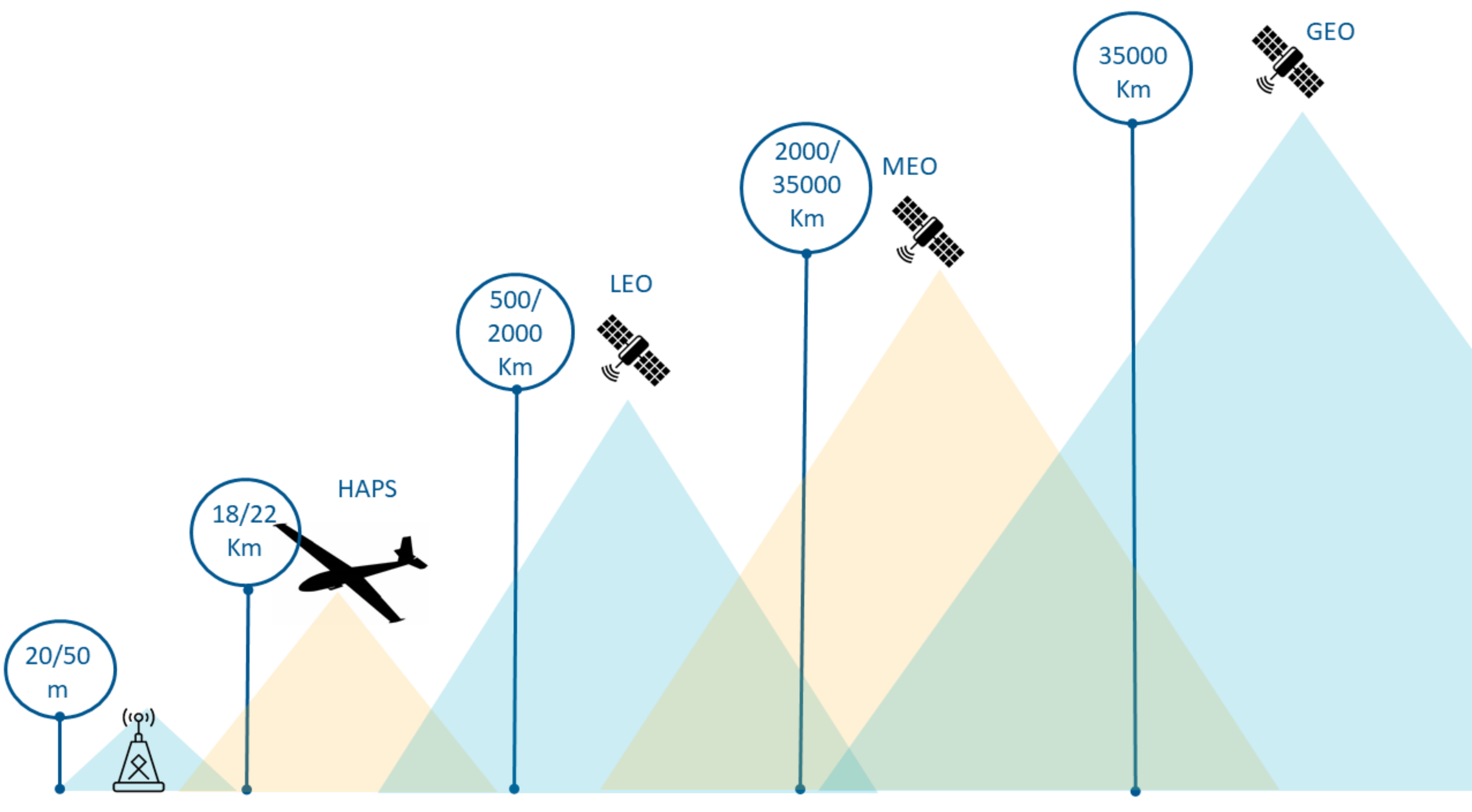
[1] Journal of Aerospace - High-Altitude Platforms — Present Situation and Technology Trends
[2] https://www.dlr.de/content/de/artikel/digitalisierung/projekt-hap.html

Landscape

A long-standing objective for mobile operators worldwide, universal cellular coverage would reduce the digital divide between those that can access connectivity services and those that cannot.

The challenge is how to do this economically. Many regions without service have either very low population densities or are difficult to reach with terrestrial-based radio systems. Geographical and topographical constraints mean that it can be very costly to deploy base stations and revenues would be insufficient to justify the investment. The deployment and maintenance of extensive terrestrial networks in rural locations can also have a significant environmental cost.

Rather than deploying expensive and under-utilised terrestrial base stations, it could be possible to create a cost effective and environmentally sustainable platform that delivers an equivalent level of coverage and capacity from the air. Air-based mobile coverage solutions may also improve the resilience of cellular connectivity during natural disasters or other major disruptions to land-based networks. For these reasons, the industry is exploring satellite and high-altitude platform systems (HAPS).



Satellite systems

Satellite systems can be categorised according to the orbits that they utilise, such as geostationary, middle-earth, or low-earth orbits (GEO, MEO, and LEO).

Geostationary Orbits (GEO)

GEO satellites take advantage of a unique orbit in which the circular velocity of a satellite, when located above the equator at 35,000km altitude, is exactly matched to the rotation of the earth. This results in the satellite appearing to be at a fixed location in the sky relative to an observer on the ground.

These systems are well established and form the basis for both satellite television broadcasts and fixed connectivity services. GEO satellites can work with low-cost receivers, such as a parabolic dish, which are pointed to a fixed location in the sky, without the need to rely on any costly tracking device. However, the disadvantage is that when communicating over a distance of 35,000km the time-of-flight becomes significant and the satellite's beam is dispersed over a large surface area. This means that GEO satellites are not appropriate for bidirectional delay-sensitive services, and they are not able to provide as much capacity per unit area as terrestrial systems.

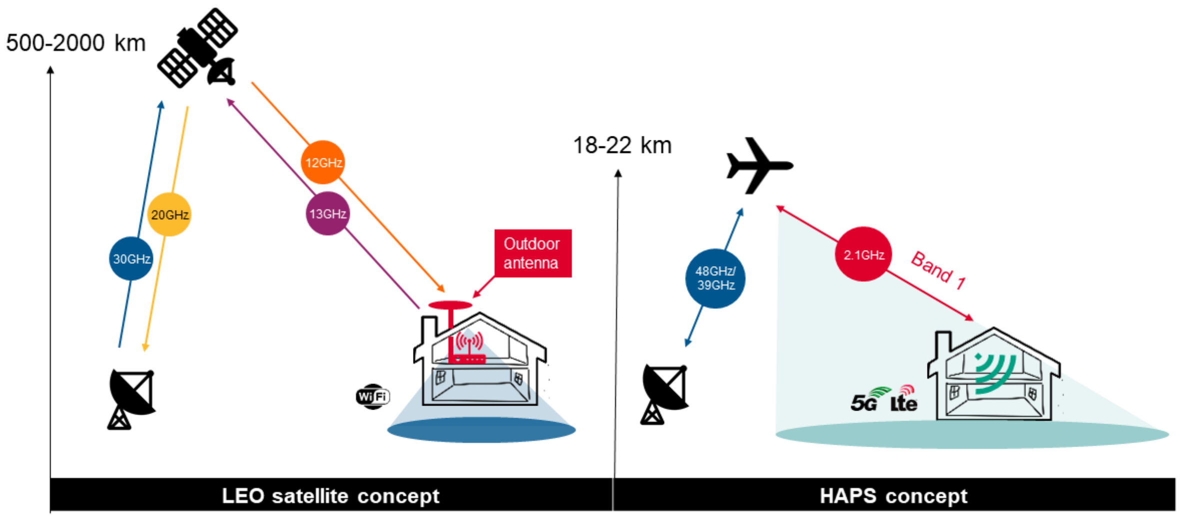
Low and Medium Earth Orbits (LEO and MEO)

Low and medium earth orbits are both characterised by satellites that are moving relative to a fixed point on the earth. Whilst LEO satellites are in orbits of less than 2,000km, MEO orbits are in the range from 2,000km up to 35,000km (the orbit of the GEO). In either case, the orbits can be either equatorial, polar, or inclined – a system may use a combination of each to provide truly global coverage.

Lower altitudes lead to faster relative velocities, such that a satellite in a LEO orbit may pass over a fixed point on the earth in a time span of less than 10 minutes of visibility.

The advantage of lower orbits, such as LEO, is that the time delay introduced from the time-of-flight is much less than a GEO satellite and beams that are projected from a lower altitude can be more focused, enabling a greater capacity per unit area on the ground. However, there are also downsides – many individual LEO satellites are necessary to deliver continuous connectivity, and beam tracking at either the satellite or the ground receiver is essential to maintain a good link budget and support mobility.

LEO and MEO satellite constellations are used today to deliver services, such as global positioning, mobile communications, and IoT services.



High altitude platform systems (HAPS)

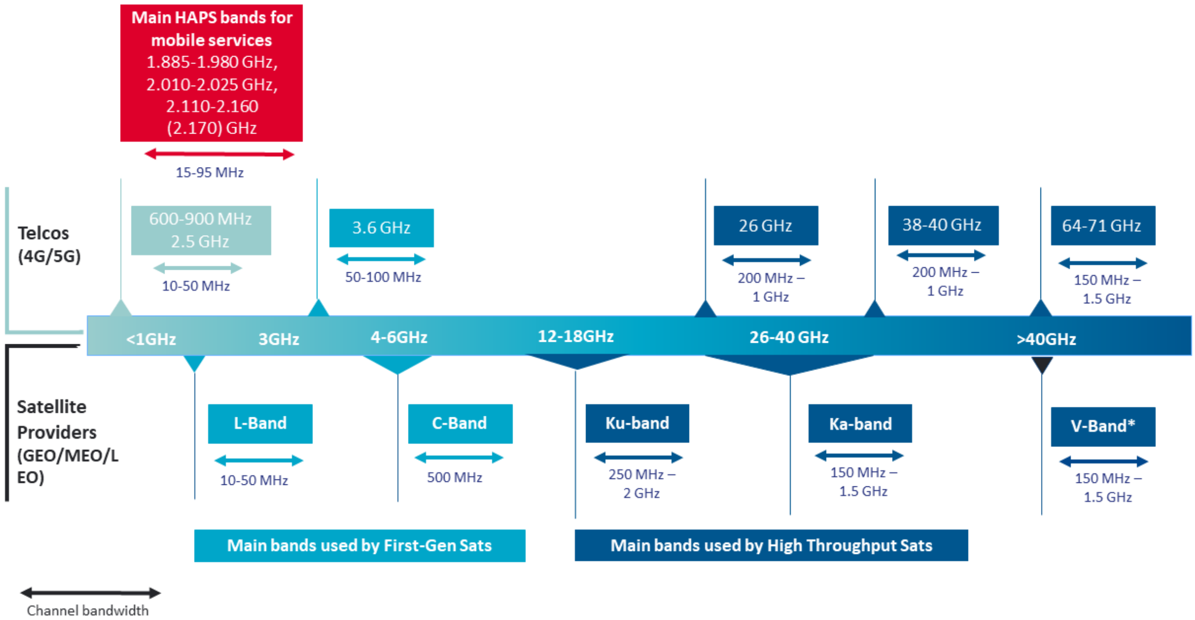
Unlike satellites, high altitude systems are aircraft that fly or float in the stratosphere, typically at altitudes of around 20km. They could be high-altitude free-floating balloons, airships, or powered fixed-wing aircraft that use either solar power or an on-board energy source. All systems are unmanned, operating in a challenging environment in which solar radiance is high and temperatures can be very low, and are designed to be airborne for long periods of time. For systems that are intended to deliver coverage to a fixed location on the ground, the platform must have power in order to remain 'on-station'.

Much closer to the earth than a satellite, a HAPS platform can project smaller beams onto the ground from a directional antenna, increasing the capacity delivered per unit area [bits per second per km^2]. However, the aircraft must consume significant energy to remain airborne, whilst also providing sufficient residual energy to power its payload. Therefore, payload power consumption, mass, and the available energy supply are all critical factors in the system design.

The table below shows various characteristics of satellite and HAPS target deployments, in terms of deployment and operational complexity, overall system capacity and latency performances.

		Satellite for global coverage	Timer per orbit (Hours)	Time in site per gateway	Latency: RTT (ms)	Mass (Kg)	Lifetime (years)
Global Coverage	GEO	3	24	Always	600/700	~3500	15
	MEO	10-30	5-12	2-4 Hours	<150	~700	12
	LEO	100+	1.5	15 Minutes	<50	5-1000	<5-7
Spotted/ Regional Coverage	HAPS	1 aircraft ~ 12 731 Km² (70 Km radius assumed in this paper)		Always	<10	< 320 (Balloon) <100 (Aircraft)	> 5 (Balloon) > 8 (Aircraft)

In terms of spectrum, many next generation satellites are migrating towards mmWave for improving capacity performance at high distance scenarios. While, HAPS benefits from a lower distance from the Earth which allows to provide mobile services to standard mobile devices using licensed bands in low frequencies (below 6 GHz, indicated in the red box in the figure below). A coexisting solution between HAPS and Terrestrial network is a must.



The following chapters explore the potential opportunities for HAPS platforms to deliver communication services, while considering the economic aspects related to maintaining a fleet of aircraft, and the state-of-the-art platforms that could deliver a viable service.

Potential Use Cases

Benefits and opportunities

Any new technology generates new business opportunities, if it enables new or improved services and/or reduces cost. In this case, HAPS has the potential to serve unconnected mobile broadband users, fixed wireless customers and companies adopting IoT devices.

HAPS are versatile, which enables them to support various use cases. A platform can be adjusted to meet a specific demand in terms of capacity and coverage area, and aircraft can also be sent to cover a location at short notice. HAPS technology can scale up and down to connect a whole country or continent, one region or just one area. Modern antenna beamforming capabilities allow for the direction of capacity to desired target areas. For example, HAPS capacity can either be distributed to a wide area to provide blanket coverage or be focused on smaller areas of interest.

HAPS can support the existing network infrastructure, potentially enabling the faster deployment of connectivity at lower cost in some situations. They can deliver LTE, 5G and potentially the next network evolution. Further, there are no special requirements on the user equipment (UE) for a given radio network standard: a normal smartphone can be used instead of proprietary UE. The system can be upgraded by changing the airframe and fitting new antenna to the aircraft. System updates and maintenance service can be centralised and conducted during a refuelling pause, without any need for staff to travel to distant sites.

As they operate in the stratosphere, HAPS are not visible to humans. As such, they could be used to provide coverage in areas where people are concerned about the visual impact of terrestrial infrastructure on the landscape.

HAPS that use liquid hydrogen may be able to remain airborne for longer periods relative to aircraft powered by aviation fuel as the as the energy density of liquid hydrogen is greater.

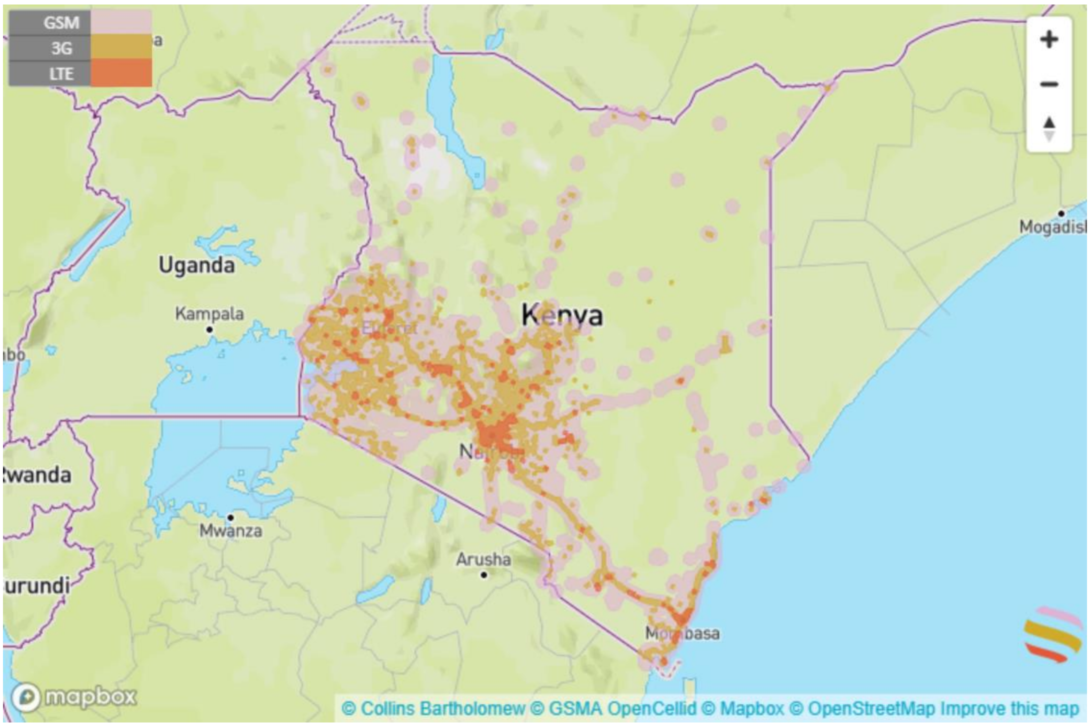
HAPS can support a variety of use cases for both developed and developing markets, including:

- Greenfield coverage
- White spot reduction
- Emergency communications and disaster recovery
- The Internet of Things (IoT)
- Temporary coverage for events and tourist hotspots
- Fixed wireless access
- Connectivity for urban air mobility and drones
- Private networks
- Terrestrial site backhaul

Greenfield coverage

Today, practically all countries worldwide have some mobile coverage and the majority of the global population is already connected. However, some large geographical areas lack any type of cellular infrastructure. These areas can be considered as greenfield for mobile networks.

The picture below illustrates mobile operator coverage in Kenya. It shows that more than half of the country's landmass is without basic connectivity.



Source: GSMA, hhts://www.gsma.com/coverage

According to UNESCO, 43% of the world's households do not have internet access, and roll-out of terrestrial networks is slowing[3]. An affordable internet connection provides education, access to

[3] https://en.unesco.org/news/global-education-coalition-facilitates-free-internet-access-distance-education-several
https://en.unesco.org/news/new-report-global-broadband-access-underscores-urgent-need-reach-half-world-still-unconnected

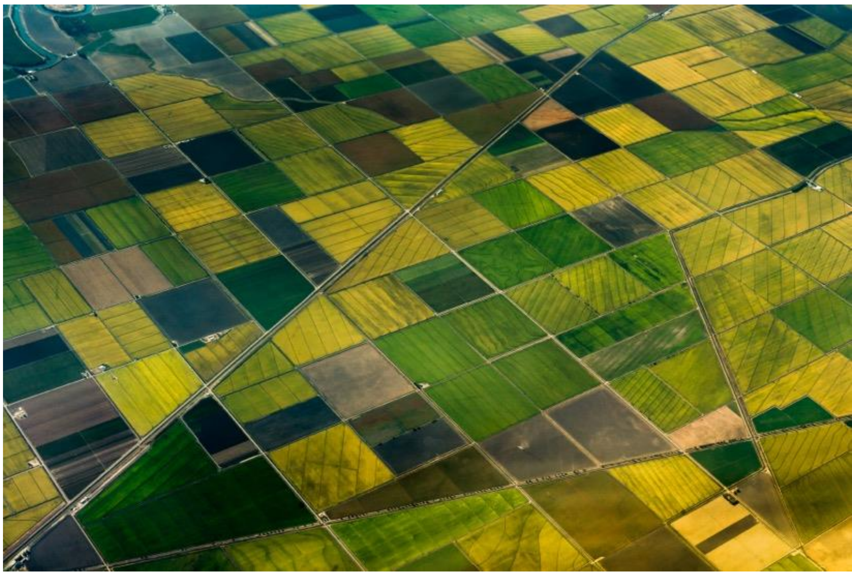
valuable information, various services, and the opportunity for businesses to interact with buyers and sellers globally.

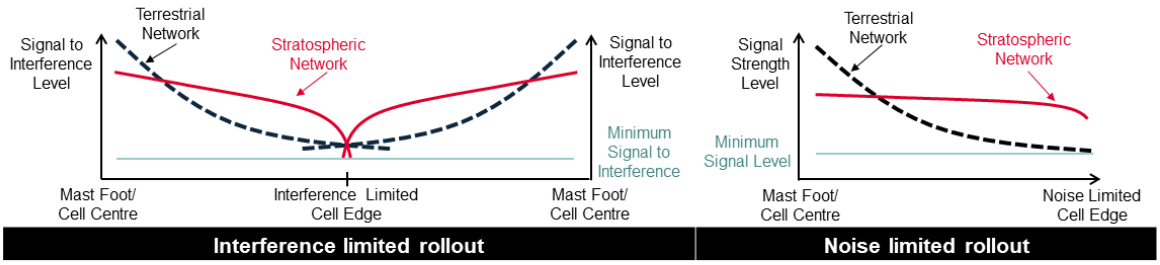
Deploying conventional wireless access network infrastructure in such locations is a challenge for the operators due to lower population density, terrain or lack of power and telecommunication infrastructure.

For greenfield coverage, a relatively low number of HAPS aircraft could cover a wide area with sufficient capacity. If necessary, the service could be tailored to offer Internet connectivity via HAPS for limited hours per day/week. The supporting ground infrastructure for HAPS could be located in an area with higher population density.

White spot reduction

Compared to greenfield areas, white spots are typically small areas (a few kilometres) without coverage, within an existing coverage footprint. They are mainly the result of terrain obstacles. Even in developed countries where geographical coverage is typically above 90%, users at a cell edge often experience modest network performance (see graphic below), this is typical for rural scenario.



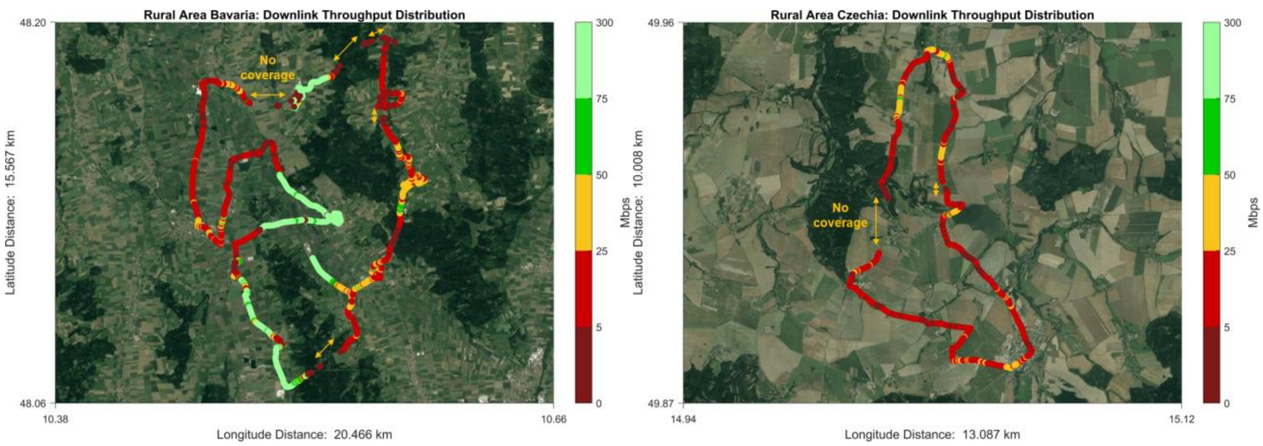


Further, network economics and planning constraints can make it challenging to cover rural areas with terrestrial networks. As many people experience while travelling via train, car or bus, there can be frequent connectivity interruptions due to patchy coverage. Yet commuters and other travellers, as well as autonomous cars and trucks, require robust and ubiquitous service.

In most cases, coverage problems are the result of terrain morphology where hills and other geographical features obstruct signals from surrounding terrestrial sites. Although different operators may have different site locations, and therefore non-identical coverage footprints, large-scale terrain obstructions will impact them all. Consequently, there are areas that have equally poor coverage for all operators.

As these “white spots” are often small, non-contiguous areas, covering them would require the deployments of large numbers of new terrestrial sites, which would be economically unfeasible.

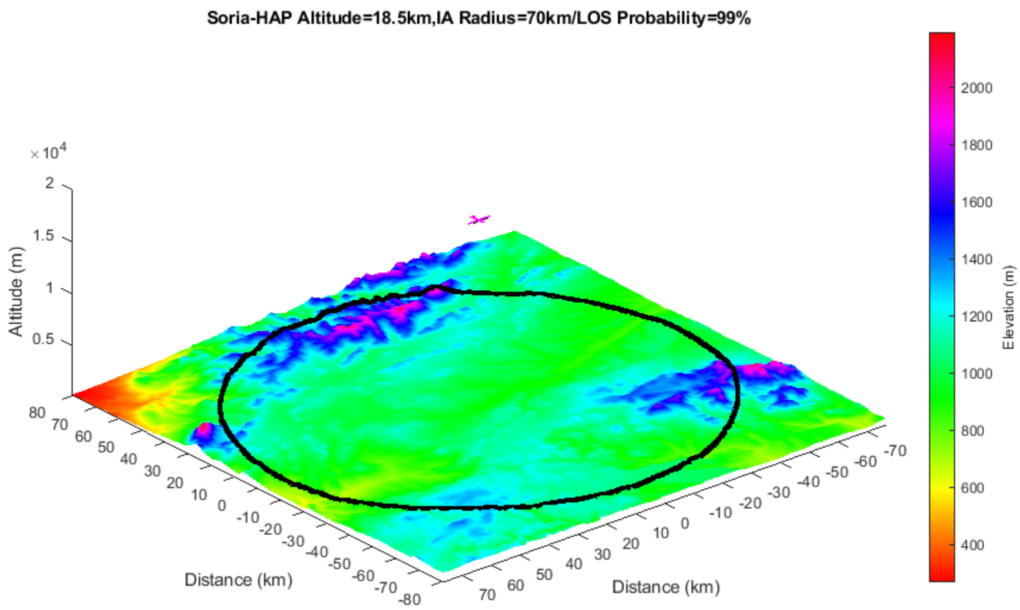
The pictures below illustrate the performance of a commercial network along randomly-chosen routes in a rural area in Czechia and Bavaria, Germany. White spots with no coverage were present in 8% and 10% of the route, respectively. In addition, there were villages with very low throughput or even no coverage, which could benefit from ubiquitous geographical coverage delivered via HAPS.



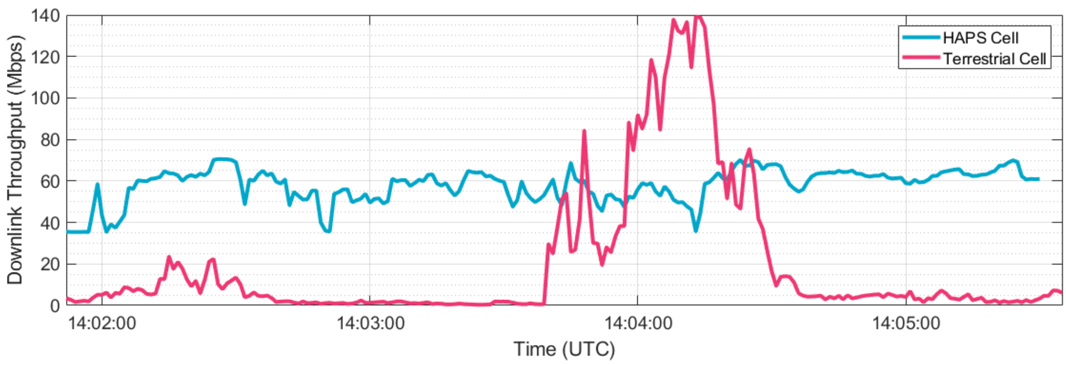
A key advantage of HAPS is the favourable radio propagation conditions afforded by the aircraft’s operational altitude, thereby allowing a high probability of line-of-sight with the terrestrial end-user devices, even in the presence of terrain obstacles, which may otherwise adversely affect terrestrial-based communications (see graphic below). HAPS could also improve coverage in coastal areas and connect boats out at sea, out of reach of terrestrial networks.

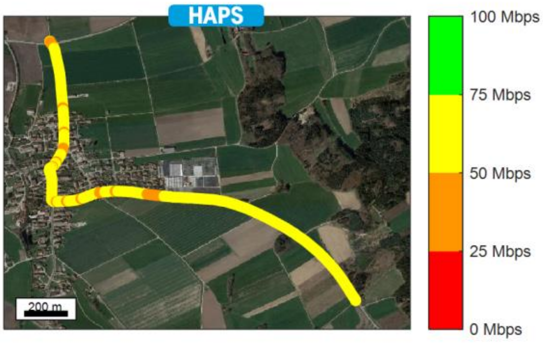
HAPS' ability to provide close to 100% geographical coverage with lower latency than satellites can ensure more reliable connectivity along traffic corridors. A HAPS system can also bring connectivity to edge computing facilities on the ground to further reduce the latency for close to real-time services.

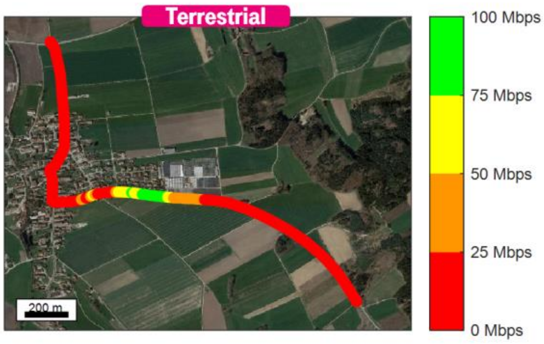
The following picture shows coverage simulation for the Soria region in Spain, which could be served by single HAP and would provide line of sight connectivity for 99% of the served area.



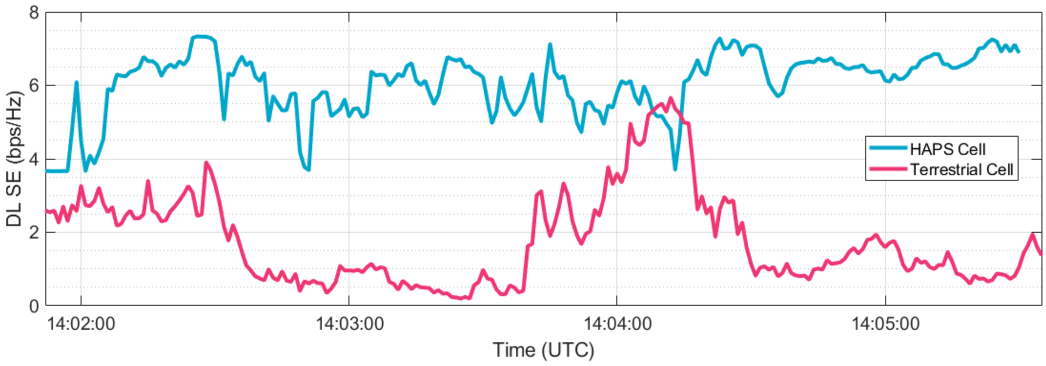
Some mobile operators have conducted practical experiments of HAPS service capability. The pictures below illustrate the throughput performance during a drive test along countryside roads, through a village, i.e. in a typical white-spot area. Measurement is done using standard smartphone user equipment inside a vehicle, comparing HAPS and terrestrial network service.







While HAPS might not offer the same peak throughput as terrestrial network in locations that are near a cell site, it demonstrates excellent spectral efficiency (SE) throughout the measurement area.



The measurement results suggest that HAPS can provide wide area coverage with homogenous performance, whereas terrestrial network service performance fluctuates a lot depending on distance from serving site.

HAPS can be easily integrated into the already existing terrestrial network and that should be the requirement. As spectrum is a scarce and expensive asset, HAP solutions need to use spectrum in an efficient manner that allows for co-existence with terrestrial networks. In this use case, both technologies support one another to realise the full network potential.

HAPS is the only practical means to make extensive use of mid-band frequencies (e.g. 2.6 GHz) and in rural areas. While the 2.6 GHz frequency band is currently used in urban areas as a capacity layer, it is typically not deployed in rural areas due to its propagation characteristics, as it is more affected by terrain obstacles. This band could be fully utilised by HAPS, even in rural areas (thanks to near line of sight propagation) and without interference to the terrestrial network. For the same reasons, mmWave bands could be used for fixed wireless access (FWA).

HAPS are set to play an increasing role in network development in 5G and beyond, operating in dynamic cooperation with LEO satellites. In their current deployment, whereby mobile site antennas are mainly tilted downward, terrestrial networks are not well suited for serving certain aerial applications (e.g. agriculture or inspection which are typically in coverage whitespots), and HAPS platforms could deliver stable connectivity even for urban air mobility users.

Emergency communications and disaster recovery

Natural disasters and terrorist attacks can disrupt terrestrial mobile networks and even emergency communication services. HAPS could help save lives by providing a communication platform for search, rescue and coordination of emergency teams. Moreover, connectivity would enable personnel to restore other critical infrastructures, such as water, transport, and energy supply.

HAPS are an excellent candidate for supporting disaster relief missions due to their wide coverage, the ability to provide continuous connectivity for many days, resilience against localised disaster events, and fast deployment. In addition, HAPS can be used to restore emergency call capability for the general public in cases where the terrestrial network is not available. One aircraft can cover a significantly larger area than a terrestrial "cells on wheels" emergency solution, and can be reallocated more easily to affected areas.

HAPS aircraft would be ready in an airport, and in case of emergency, the platform can be sent to the target area to assist with emergency recovery by providing secure and reliable connectivity. Where appropriate, a self-contained ground station that has its own power supply, such as a diesel generator, and backhaul connectivity via satellite could be deployed to support HAPS. The system could then be deployed as part of an existing emergency communication architecture to improve emergency management. The HAPS concept has already proven its worth during disasters in Puerto Rico and Peru (2017 and 2019)[4].

[4] https://www.itu.int/en/mediacentre/backgrounders/Pages/emergency-telecommunications.aspx

The Internet of Things

The Internet of Things (IoT) refers to the interconnection of a wide range of vehicles, machines, appliances, devices and sensors. The IoT can be used to optimise processes, lower costs and pursue new business opportunities based on data analysis. The role of the mobile network is to transfer captured data to an application or to other devices, where data processing is performed. Essential requirements are reliability and efficient data transfer in cases where the available power is limited. Operators may also need to provide security, privacy, and autonomic networking to accommodate a large number of devices of different types.

In industry, the IoT can be used to support data analysis and machine learning to increase automation. Some examples of industrial IoT are smart grids, smart cities, smart manufacturing or connected logistics. The IoT can also enable predictive maintenance and smart energy management with minimum human intervention. Another advantage is improved industrial safety.

Many IoT applications do not require extensive capacity; therefore, a relatively small number of aircraft with wide service area could be deployed to support even highly distributed IoT deployments. HAPS can support enhanced congestion prediction and control methods to optimise network performance. HAPS can mirror the security and privacy capabilities of a terrestrial network, while network slicing could be implemented.

HAPS could also support V2X, or vehicle to everything (infrastructure, another vehicle, network, device, and pedestrian), communications[5]. V2X connectivity can improve road safety, increase total traffic efficiency (reducing congestion etc.) and deliver energy savings through data analysis and vehicle cooperation, while enabling car-to-car communications. HAPS could provide the full geographical coverage necessary to support this use case, while also bringing connectivity to edge computing facilities on the ground to further reduce the latency for close to real-time services.

[5] https://www.itu.int/

Temporary coverage for events and tourist hotspots

Big events (usually sports events) bring crowds to a particular area, increasing demand for cellular capacity. For a couple of weeks, fans and TV production teams from all around the world may frequent an event location. HAPS are a convenient way to provide temporary coverage and capacity to locations in challenging terrain, where 100% coverage would be otherwise almost impossible.

For example, HAPS could support uninterrupted safety and video streaming services to the Dakar Rally (held in the dunes of Sahara, Saudi Arabia or South America), the Tour de France (wide event area) or even the Winter Olympic Games (ubiquitous coverage even in the mountains). HAPS could also support cross-country skiing races in Lapland, such as Vasa race (Vasaloppet) or 220 km long extreme race Nordenskiöldsloppet.

The main advantage of HAPS for this use case is ubiquitous coverage, which can't be achieved by any other technology in such atypical terrain. The coverage would enable new forms of streaming, such as from drones. The HAPS service area radius and cell capacity can be adjusted flexibly to address the specific demands of the event.

Popular tourist islands also see a short-term increase in capacity demands, generally in areas where expanding terrestrial network poses a challenge. HAPS could cover popular hiking areas in peak season to provide an internet connection to visitors searching for maps and other information. The platform could be flexibly reallocated from one location to another according to customer demand to serve remote islands in the summer and provide coverage in the mountains during the winter season.

Fixed wireless access

Although there is a big push to increase the availability of fibre-based broadband, it is not feasible to provide ubiquitous fibre connectivity for all customers, especially in rural areas. Fixed wireless access delivered via HAPS could provide adequate data rates to households without any wired connectivity. The lower operating altitude and smaller service footprint means HAPS can provide higher capacity and lower latency than satellite-based services.

A HAPS mmWave solution could compete with fixed-line services by providing ultra-high-speed broadband to remote rural areas. HAPS could be the only realistic way to backhaul mmWave wireless connectivity in areas where fibre is prohibitively expensive to introduce and maintain. FWA services can support rural development by providing fast access to information to homes and businesses.

Connectivity for urban air mobility and drones

Set to be commercialised in the near future, urban air mobility (UAM) is an emerging system to transport passengers and goods in densely populated urban environments. UAM systems may be remotely piloted (RPAS) and could eventually be autonomous[6].

Both RPAS and autonomous systems need stable command and control and telemetry connectivity for flight operations before, during and after the flight. In addition, there is demand for data services for onboard infotainment and passenger connectivity.

Unmanned aerial vehicles, commonly referred to as drones, are already used for industrial applications, such as site inspections and security. They could also be used for parcel deliveries ranging from the provision of urgent medical supplies to bulk transport of small parcels.

Currently, a combination of legislative constraints and the relatively short reach of remote control connectivity means most operations are limited to visual line of sight (VLOS) conditions. However, many potential applications, such as power line inspections and medical deliveries between hospitals, will require beyond visual line of sight (BVLOS) operations. BVLOS operations depend on wide area connectivity, as well as air traffic management[7].

Terrestrial mobile networks are optimised to provide contiguous coverage at street level. Their antenna's main beams are tilted towards ground. As a result, the mobile device on an UAS is served by random cells, meaning the service quality for aerial applications may not be very stable. This increases the signalling load on the network and leads to a sub-optimal user experience.

HAPS can address this issue. Since the coverage is projected from above, rather than from the ground, all UAM and UAV applications would be served by a well-defined cell footprint and be free from terrestrial obstructions, allowing for continuous coverage throughout the entire flight mission.

[6] https://www.easa.europa.eu/what-is-uam
[7] https://www.caa.co.uk/Consumers/Unmanned-aircraft/Our-role/An-introduction-to-unmanned-aircraft-systems/

Private networks

In both the public and private sectors, there are cases where an organisation may need a private wireless network. This requirement may be temporary or permanent, static or vehicular, and may be local or global in nature. Potential applications of a HAPS-enabled virtual private network could include:

- Mining industry applications
- Smart farming where field multispectral photogrammetry data is fed to the cloud for analysis
- Monitoring wind farms, in place of current unreliable satellite services
- TV production support for wide area event coverage

In each case, HAPS could provide permanent or temporary services, according to requirements from the customer without the need for custom end-user devices.

HAPS would offer superior capacity and latency capability compared with satellite solutions. Edge computing features can be located in a ground station and a distributed core network could be incorporated, where necessary.

Terrestrial site backhaul

In specific areas, it can be difficult to deploy backhaul links to bring base stations and edge computing facilities online.

For example, archipelago islands and other remote areas may not generate enough traffic to warrant the costly deployment of fixed line fibre connectivity, while terrain and weather obstacles may hinder terrestrial microwave backhaul. Also, fixed line solutions are not always feasible for temporary use, where the need may be seasonal or only for short period of time.

Some mobile operators and technology partners are considering the use of HAPS as part of backhaul solution for portable base station and industry use cases[8]. For these applications, mmWave and free space optics (FSO) communications solutions could allow for a relatively lightweight payload, allowing use of smaller HAPS vehicles, which could be connected in a mesh network configuration. FSO is mainly

8 https://www.nttdocomo.co.jp/binary/pdf/corporate/technology/rd/docomo5g/20200122_01/DOCOMO_6G_White_PaperEN_20200124.pdf

applicable for inter-HAPS communications, but also can be applicable to ground communications in certain regions.[9]

[9] https://www.itu.int/en/myitu/News/2020/04/24/09/24/Connectivity-from-the-stratosphere

HAPS Implementation Scenarios

As with any complex infrastructure programme, there are different implementation scenarios in which a HAPS platform could be deployed. The chosen mode depends on the primary service use case, as well as the business motivation.

At a high level, the main implementation scenarios are likely to be: dedicated, shared, neutral host and governmental, potentially in combination.

Dedicated

In a dedicated deployment scenario, a mobile operator implements a HAPS platform for its own use to gain business advantage over competition. Service differentiators may be time to market and enhanced service coverage.

Shared

A HAPS platform may be deployed as a joint venture of participating mobile operators. This model allows for lower capital investment and operational cost burden, as the platform cost is shared among operators.

A single physical platform could be operated as a MORAN (multi-operator radio access network) where each operator would use its own spectrum resources, or as MOCN (multi-operator core network), where the spectrum is also shared[10].

Neutral host

In a neutral host model, a private entity would deploy and operate the HAPS platform and offer it to operators in a “platform-as-a-service” model. The neutral host would implement and operate a multi tenant platform to enable a profitable business model. The neutral host could have a background in aviation or infrastructure, such as Stratospheric Platforms Limited, Airbus, or tower infrastructure companies.

As major part of the HAPS operational concept involves technologies from outside of the telecommunications realm (see later section), a neutral host or shared operator approach could be a successful model.

Governmental

A government may deploy HAPS for civilian or military use. An example of this would be a public protection and disaster relief (PPDR) communications system, operated by a governmental body or wider entity, such as the European Union.

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[10] https://www.gsma.com/futurenetworks/wiki/infrastructure-sharing-an-overview/ and https://ra-advisory.dk/onewebmedia/nwshare.pdf

Hybrid

There will be cases that combine the aforementioned scenarios. For instance, a national mobile operator may deploy HAPS, and as a host operator, it can offer the platform to other operators as a managed service, knowing that it can address white spots common for all operators.

A shared joint venture may be privately funded by participating operators, or be partially financed by governmental funding (e.g. The Shared Rural Network[11], UK).

A HAPS platform may also serve as a host of non-telecommunications services, such as aerial sensing, monitoring and map imagery, providing synergies for a governmental deployment.

[11] The Shared Rural Network https://www.mobileuk.org/shared-rural-network

HAPS Technology

As they operate in the stratosphere at an altitude of about 20km, HAPS face different constraints to base stations on the ground. Being a commercial unmanned aircraft, HAPS faces the same challenges as other unmanned aircraft systems, such as navigation, energy and communications. Research and innovation in specific technologies, such as advanced materials (durability, costs, weight), energy (solar, hydrogen, batteries) and artificial intelligence (vehicle automation), are enabling the development of HAPS.

Experiments over the past 20 years have involved several different designs of HAPS: projects and trials have explored different types of aircraft, all with different characteristics addressing specific technological aspects. The technological challenges to overcome include achieving a durable lightweight structure, energy storage, thermal management, system reliability, navigation, endurance and safe operations at lower altitude. The platform dimensions, the degree of positioning control, the maximum payload weight/size/power capabilities, as well as flight autonomy, typically determine the suitability of a given platform for a given use case.

Aside from the technical suitability to meet specific requirements arising from the use case, the type of platform also has a major impact on business-related aspects. The variety of use cases that may be served by HAPS, the variety of platforms under development, as well as the number of specific technologies involved in building and operating these platforms, presents a large business opportunity for many industries.

Aircraft

The need to travel to and from the stratosphere presents challenges that determine the design of HAPS and their payloads. Thermal management is quite important due to the drastic difference in the temperature between the ground and the operational altitude, direct solar radiation and day/night temperature cycles. In the troposphere, the temperature decreases with altitude, but then increases in the stratosphere, so the aircraft components need to support excursion from +40 to –50 degrees Celsius. In the stratosphere, the temperature ranges between –15 C and –3 C. The low air density demands structures with large wingspans for lift or large total volume for buoyancy. These structures need to be several times larger than would be necessary at ground level, making it difficult to achieve low weight structures with high endurance and creating operational challenges, such as withstanding gusty winds conditions, and providing storage for payload and other onboard equipment.

However, operating in the lower stratosphere has the advantage of a reduced average wind speed, thus less power is needed for aircraft propulsion and station keeping, and longer flight times and operational areas can be achieved. The most vulnerable part of the flight is the ascending and descending where the weather conditions could have a damaging impact on lightweight platforms with low power propulsion. In addition, the unmanned aircraft has to cross controlled airspace where there is potential of collision with other aircraft: most of the HAPS launches to date have been taking place in more isolated areas.

Moreover, wind and jet streams can impact the operation of HAPS. There are significant differences in platform requirements and achievable flight times (or payload weight) between regions and seasons: the greater the distance from the equator, the worse the conditions. Winter and autumn are the worse periods, notably in terms of daily insolation. These factors may even limit the applicability of some platform types. As a result, the energy generation and storage systems of HAPS, both for the propulsion and supply of their systems and payload, are very important. The aircraft typically rely on hydrogen fuel and/or solar power.

HAPS can be classified as aerodynamic (or heavier-than-air, e.g. fixed wing/airplanes) and aerostatic (or lighter-than-air, e.g. balloons and airships). These two classes are more or less suitable for operation in different regions and for specific applications or use cases.

Balloons (e.g. Google Loon) are small and lightweight, which simplifies some operational aspects. However, there is no means to accurately maintain control of their positioning over a specific area and they have typically low power and cargo capabilities (10s of watts, low 10s of kg), which limits the complexity of payloads that may be hosted and typically mean capacity and/or availability limitations. In terms of autonomy, flights of a few months (for typical payloads and favourable areas of operation) can be achieved, and were demonstrated operationally by Google prior to the closure of project Loon.

Fixed wing (e.g. SPL, Airbus Zephyr, Softbank HAPSMobile, Skydweller SolarImpulse) platforms can be positioned precisely and have larger weight, power and flight time capabilities than balloons. That enables the support of more complex applications. On average, cargos in the mid/high tens of kg and power above few hundred watts are achievable. They can also stay airborne longer than balloons, with flight times of several months in cases where the weight of the payload and power requirements are not large. However, systems under development promise to increase these capabilities above 100kg and several kW (depending on the flight time). The aircraft's wingspan is large (even larger than 60 metres), and they require specific facilities to land/take-off and for maintenance.

Airships (e.g Thales Stratobus, Sceye, Altran Ecosat) are the largest platforms, with higher capabilities in terms of payload weight (several hundred kg), power (even above 10kW), and autonomy, which may reach up to a year (as in any other platform, largely dependent on payload requirements and area of operation). As with fixed wing solutions, they offer precise control of the positioning of the platform. However, the size of these systems introduces additional operational complexity, as they may exceed 100 metres in length and 30 metres in height, which requires quite specific installations to manage their operation.

Hybrid approaches mixing aerostatic and aerodynamic principles are also under consideration and may lead to newer solutions with characteristics in-between those of airships and fixed-wing craft.

Apart from the general characteristics discussed above, many other factors may need to be taken into account, depending on the specific application requirements and regulatory constraints. These include:

- Speed (both horizontal and ascent/descent),
- Deployment range (linked to energy source and battery systems),
- Limitations for take-off and landing (locations, weather),
- Flexibility to host different payload types and evolve over time for newer applications,
- Safety-related aspects (e.g. applicable to descent in case of catastrophic failure), and other operative factors (such as mean time to repair (MTTR), maintenance procedures, etc.).

Communications systems

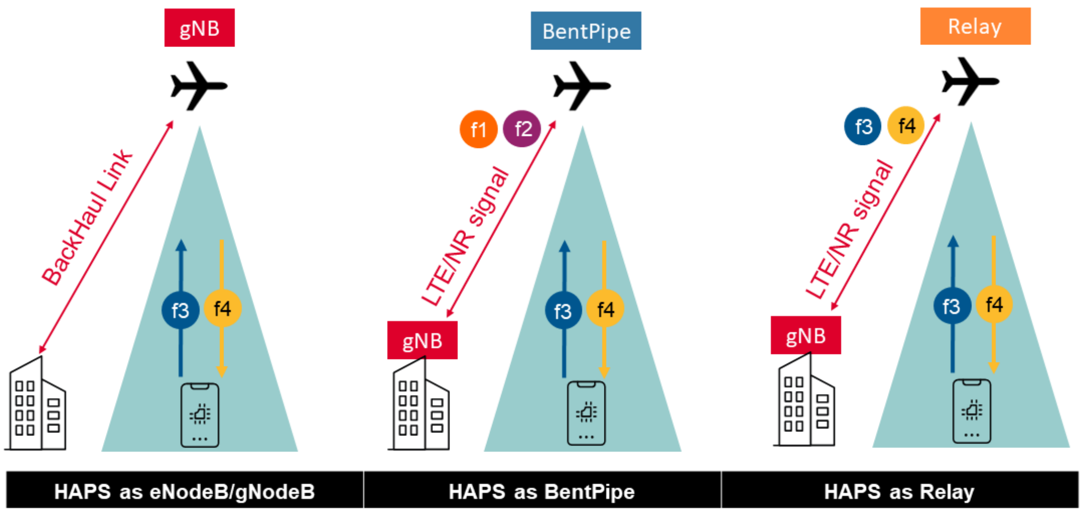
HAPS are equipped with specific technologies, such as propulsion, power management, battery storage, solar/fuel systems, safety, telemetry and flight/payload control and the on-board payload and specific subsystems. These systems are governed by the type of platform.

By contrast, on-board payloads are quite specific to the application (or applications, as there is potential to mix payloads for different simultaneous services), and may be quite different in terms of size, power and weight requirements. Cameras, sensors, radar, other imaging systems, IoT-specific modules, radio access equipment (RRH, baseband, antennas) and radio transmission equipment may be required, depending on the use case.

The operative conditions in the stratosphere mean it is generally not possible to employ straightforward off-the-shelf communications equipment. The low air pressure, temperature cycles, vibration and relative movement of the platforms, in relation to receivers in the ground or other platforms (when inter-HAP links are considered in system design), need to be taken into account.

The communications equipment required will depend on the type of access (fixed/mobile), mobile generation in case of cellular services, frequency or frequencies employed, service and quality of experience and the coverage area of operation. Baseband hardware may be on-board, which may require pooling for high traffic applications. Or the baseband could be kept on the ground, employing the HAP as a repeater or even, with a similar structure to that of a satellite, translating in frequency and amplifying signals to the ground. The decision on where to deploy the baseband will depend on the use case to balance the interplay between capacity, autonomy, on-board complexity and power/weight/size considerations.

Different communication topologies considered for HAPS are outlined in picture below.



Regulation/Spectrum/Standards

This section will provide a high level overview of important regulatory considerations for HAPS, including spectrum availability and usage, together with the development of standards.

Aviation authorities and regulations

Most civil aviation authorities define the regulated airspace as that below an altitude threshold of 60,000ft (FL600, 18.29 km). This is also the technological limit for some of the services provided by the air navigation service providers (ANSPs). When an aircraft is operating above 60,000ft, it is no longer managed by traditional air traffic management (ATM) systems, which are also unable to manage and interact with unmanned aircraft.

In Europe, an unmanned traffic management (UTM) system called U-Space is supposed to manage UAS, but only in the defined, controlled and uncontrolled airspace classes (A-G) below 60,000ft. In Europe, there is a vision of a unified single sky: the first EASA regulation for the U-Space was released in 2021, but is not in effect yet.

There is also a need for space traffic management (STM) that manages all routine operation above 60,000ft. Such a concept is in the explorative, discussion phase and it is not defined. But future regulations might cover STM and the required services, mandating certain on-board applications, such as identification and tracking.

Note that each state has sovereignty over the airspace above its territory, and airspace management may be given to one or more service providers depending on the national model. At the moment, in absence of a regulatory framework, operations of HAPS are handled in an exceptional manner in cooperation with the local authorities. In addition to traffic management, HAPS will need to comply with other generic regulations, such as safety, certification and integration with other traffic, to mention the most important ones. An increase in the number of HAPS operations would strengthen the case for a regulatory framework for operation above 60,000ft, but there are no concrete plans yet in Europe.

Spectrum

It was at the World Radiocommunication Conference 1997 (WRC-97) that spectrum was first discussed for HAPS. Since then, most WRCs have addressed the issue and there are a number of provisions in place relating to the use of spectrum by such systems.

There are two categories of HAPS authorised to operate according to the ITU’s Radio Regulations, depending on the type of service they provide. HAPS can operate either fixed services or mobile services using specified frequency bands as shown in the table below. Note, there are many technical and regulatory conditions associated with each band:

Fixed Service	Mobile Service
6440-6520 MHz, 6560-6640 MHz[12] 21.4-22 GHz[13] 24.25-27.25 GHz[14] 27.9-28.2 GHz[15] 31-31.3 GHz[16] 38-39.5 GHz[17] 47.2-47.5 GHz, 47.9-48.2 GHz[18]	1885-1980 MHz, 2010-2025 MHz, 2110-2170 MHz[19] 1885-1980 MHz, 2110-2160 MHz[20]

While HAPS' fixed services connect houses in remote locations or provide backhaul links to base stations, HAPS' mobile services would connect directly to the user equipment, operating as a base station in the sky. For that reason, the latter is known as HIBS - HAPS as IMT base station.

As can be seen from the table above, the only frequencies where HAPS can currently act as a base station is 2.1 GHz, as covered in footnote 5.388A. That provision was approved at WRC-03. The next mention of HIBS was at WRC-19, when the WRC-23 agenda was approved.

WRC-23 agenda item 1.4 is looking to consider, in accordance with Resolution **247 (WRC-19)**, the use of HIBS' mobile services in certain frequency bands below 2.7 GHz, already identified for IMT, on a global or regional level, i.e.:

- 694-960 MHz;
- 1 710-1 885 MHz
- 2 500-2 690 MHz

Preliminary studies are ongoing in the ITU-R and in many regional groups. Any authorisation for operation of HAPS would be granted by individual administrations in coordination with their neighbours.

In all cases, technology must be developed in a way that ensures an efficient usage of mobile spectrum bands. In general, efficient co-existence between terrestrial networks and their aerial counterparts is recommended (with no dedicated spectrum for air-solutions).

[12] In Australia, Burkina Faso, Cote d'Ivoire, Mali and Nigeria, as per 5.457.
[13] In Region 2 (Americas, Greenland and Pacific Islands), as per 5.530E.
[14] In Region 2, as per 5.532AA and 5.534A.
[15] In Bhutan, Cameroon, China, Korea (Rep. of), the Russian Federation, India, Indonesia, Iran (Islamic Republic of), Iraq, Japan, Kazakhstan, Malaysia, Maldives, Mongolia, Myanmar, Uzbekistan, Pakistan, the Philippines, Kyrgyzstan, the Dem. People's Rep. of Korea, Sudan, Sri Lanka, Thailand and Viet Nam, as per 5.537A.
[16] Globally, as per 5.543B.
[17] Globally, as per 5.550D.
[18] Globally, as per 5.552A.
[19] In Regions 1 (Europe, Middle East, CIS, Mongolia and Africa) and 3 (APAC and Iran), as per 5.388A.
[20] In Region 2, as per 5.388A.

Standards

As terrestrial networks evolve to meet the requirements of new and more demanding use cases, standardisation efforts, with particular reference to 3GPP, are proceeding towards an integration of non-terrestrial access into the standard 5G system. This will take place with 3GPP Release 17.

Building on top of preliminary study items on service requirements, the activities have addressed the radio implications for 5G New Radio and identified solutions to cope with protocol, architecture and network operation issues. As a result of this effort, non-terrestrial networks will become a standard 5G access mechanism.

However, the lack of HAPS industry contribution in study items and specification activities may lead to a loose focus on addressing HAPS-specific issues, which may in turn delay the availability of effective standard products in the market. Greater involvement by HAPS industry players in standardisation activities could be required.

HAPS Business Model Scenarios

As previously discussed, HAPS use cases and implementation scenarios will differ based on local market requirements, the regulatory situation, the geography, economic development, and other parameters specific to each deployment. There is unlikely to be an one-fits-all solution. Different operational and business models will be required for emergency services than for the provision of permanent and continuous coverage over certain area.

HAPS could become a key part of the future network ecosystem, complementing terrestrial and other non-terrestrial networks. To achieve this target, the complexity must be reduced and a turnkey operational model established to make HAPS easy for telcos and other potential customers to use, or integrate into their existing networks and products.

In order to achieve this target, a new ecosystem, partnerships and alliances (e.g. aerospace, telcos and government) need to be built and maintained, while a new type of infrastructure providers - flying tower companies – need to be established (see next section).

Value chain

The HAPS value chain has five key players:

1. **R&D players** that own the IPR and have developed successful prototypes. They will provide other key players with reference designs and specs, which they will monetise through licensing.

2. **Manufacturers**: The production cost baseline will play a major role in the overall cost of HAPS, its availability, and capabilities.

3. **Flying tower companies**: As the player that coordinates the procurement of aircraft and service delivery, flying tower companies have an important role in the value chain. They are likely to define the antenna specs and details, rather than opening up the choice for telcos, as this will allow for sharing and multiple applications on top of the HAPS – the flying tower companies will want a highly diversified service offering.

4. **Antenna suppliers** offering commodity equipment, which is practically available today.

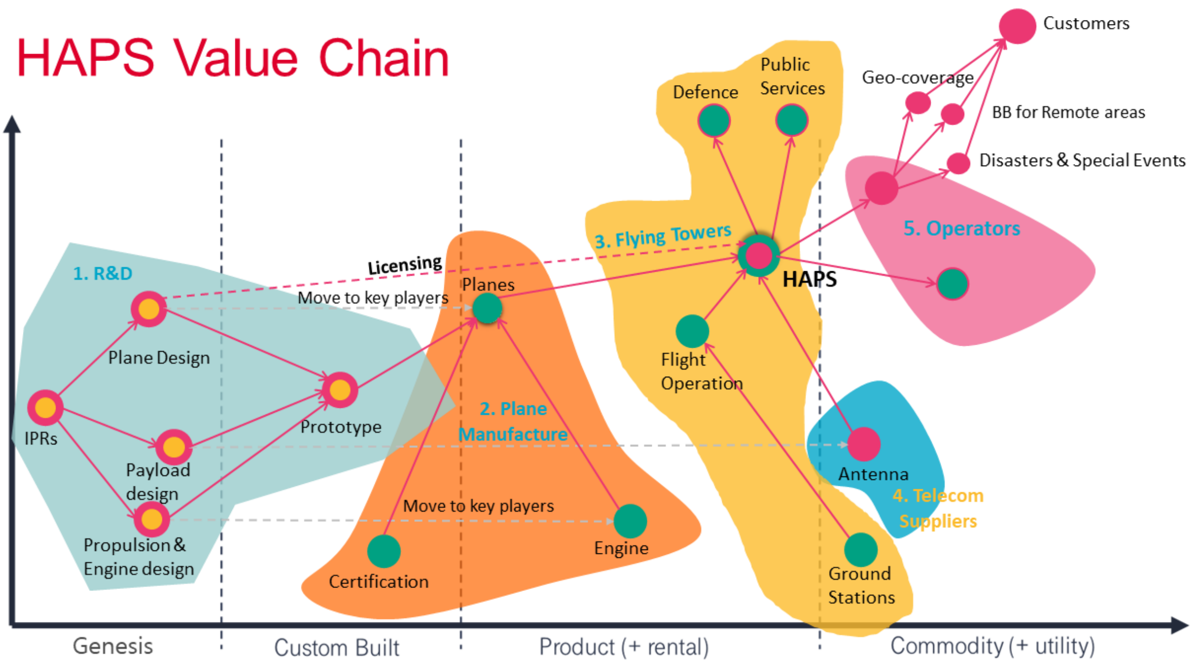
5. **Mobile network operators** will play an important role, as they deliver telecoms services to customers and will be one of the main cash flow sources in the chain.

There are also three key customer groups in the value chain:

1. Operators, delivering to their end users

2. Civil services: that support weather, monitoring forests, remote area monitoring, etc.

3. Defence use cases



Operations & business models

The operations and business models of flying tower companies will be based on the implementation scenarios and use cases described in the previous chapters. Flexibility will be necessary to meet different HAPS deployment situations.

Their product and service portfolio will consist of the following elements:

1. Flying tower (minimum scope)
    a. Aircraft acquisition, financing and maintenance
    b. Airport infrastructure
    c. Flight operations incl. remote control
2. Ground stations and backbone
    a. Building and maintaining ground stations including mobile ground stations
    b. Ground backbone network
    c. Ground-to-air connection
3. Flying network
    a. Antenna and payload
    b. Network integration
    c. Network management

To build the above portfolio, multidisciplinary competence, including aerospace and telecommunication know-how will need to be established and productised. These competences could create a worldwide business opportunity for a new type of infrastructure provider.

Call to Action

Given the importance of global broadband connectivity (and the need to provide white spot coverage and emergency communications/disaster recovery), network operators see HAPS as a potential extension to existing terrestrial networks and possible element of the future network architecture. The mission is to connect the unconnected.

Looking at the exciting opportunities that HAPS could bring to telecoms, network operators are committed to drive innovation. However, there are still many challenges: the technology is in the research and development phase and must be further investigated within a bigger ecosystem. There are significant technology challenges that must be overcome to make HAPS competitive with alternatives in different use-cases. Nevertheless, HAPS could provide an opportunity to develop a new type of industry, combining expertise in telecommunications and aerospace in so-called “flying tower companies”.

However, preliminary cost comparisons do not provide strong evidence of HAPS being competitive with terrestrial network expansion in some scenarios. More in-depth techno-economical comparisons are required to further define what kinds of application may be most applicable for HAPS and which ones show less potential. A second version of this paper will contain a more comprehensive economic analysis, that will be published on a later date.

As and when well-defined opportunities for HAPS solutions (such as disaster recovery relief) are identified, the following elements are needed:

- Funding for R&D
- Adjustment of regulations on aviation and telecommunications
- Identification of scenarios where a commercially profitable enterprise can be demonstrated, in addition to disaster recovery
- Additional concepts as to how to integrate HAPS into future network topology, with a particular focus on spectrum coexistence between air and terrestrial networks.

As a Call to Action, we are making the following invitations:

Telco industry partners:

- Join our HAPS journey by partnering up and helping us further study HAPS to support future networks.
- Develop solutions to the challenges facing HAPS applications (especially around spectrum management and coexistence).

Aerospace and UAS industry players:

- Recognise HAPS as a new business opportunity.
- Drive technical innovation in aircraft design and UAS operations support systems to develop a sustainable carrier platform for telecoms payloads.

Regulatory bodies and government institutions:

- Understand the importance of HAPS for achieving technological progress, accelerating the economy, and providing connectivity to the people.
- Take an inclusive approach to facilitating RPAS operations in controlled airspace by jointly developing unmanned aircraft system (UAS), unmanned traffic management (UTM) and collaborative traffic management in the stratosphere (CTMS).
- Recognise the increasing demand for suitable radio spectrum resources for HAPS services.

Investors:

Explore a potentially profitable new technology and the associated ecosystem as a promising investment opportunity.

GSMA HEAD OFFICE
Floor 2
The Walbrook Building
25 Walbrook
London
EC4N 8AF
United Kingdom
www.gsma.com