High Altitude Platform Systems

Towers in the Skies

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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
- Extended coverage over the sea – providing connectivity in proximity to shores

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.

Use Case Analysis

The GSMA and its members are committed to increase the digital inclusion. In 2021 8%[1] of the global population did not have access to mobile services. Though there are many reasons for this state of affairs, the economic feasibility of connecting the unserved is usually a decisive factor.

Therefore, the economic and technical boundary conditions for terrestrial roll outs were analysed with a particular focus on the use cases of greenfield, whitespots and Fixed Wireless Access for different markets. As a result, a number of technical and economical KPIs were derived. These KPIs are important for providing a characterisation of the given scenario to the HAPS platform providers, so that they are able to understand the framework for the uses case in a given market.

Each use case has quite unique challenges and characteristics in different countries, therefore it seems improbable that a generic HAPS platform solution will be able to cater for all the different scenarios. It is highly recommended to carefully analyse a target use case by considering the geographical, social and economic aspects. As the analysis was carried out by MNOs without detailed input on potential HAPS solutions the results provide a first rough indication. However, initial discussions with different HAPS suppliers were also performed. In these discussions the HAPS suppliers indicated different cost cases that resulted in some of the use cases being viewed more positively whilst other use cases were viewed more negatively in terms of their business cases for the deployment of HAPS. Further deep dives in collaboration with HAPS suppliers will be needed in the future to draw more tangible conclusions. It is also acknowledged that the HAPS suppliers will have room for cost improvements in future, e.g. due to the maturing and scaling of the technology.

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 which 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. Fixed wing platforms 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.

Dirigibles are the largest platforms, with higher capabilities in terms of payload weight (several hundred kg), power (> 10kW), and autonomy, which can stay airborne for 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.

[1] The Mobile Economy 2021 - https://www.gsma.com/mobileeconomy/wp-content/uploads/2021/07/GSMA_MobileEconomy2021_3.pdf

Hybrid approaches mixing aerostatic and aerodynamic principles are under consideration and may lead to newer solutions with characteristics in-between those of dirigibles 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 unable to manage and interact with unmanned aircraft.

The concept of space traffic management (STM) – I.e. to manage operations above 60,000ft - is in the explorative, discussion phase and it is not yet defined. 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

The GSMA is thus calling on telcos to help further study and consider the 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[2].

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[3].

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 second version of the paper provides more insights on the technical, social and economic aspects that mobile operators are taking in account when analysing the opportunities to deploy HAPS solutions.

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:

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

Supporting mobile operators:

Platform Providers:

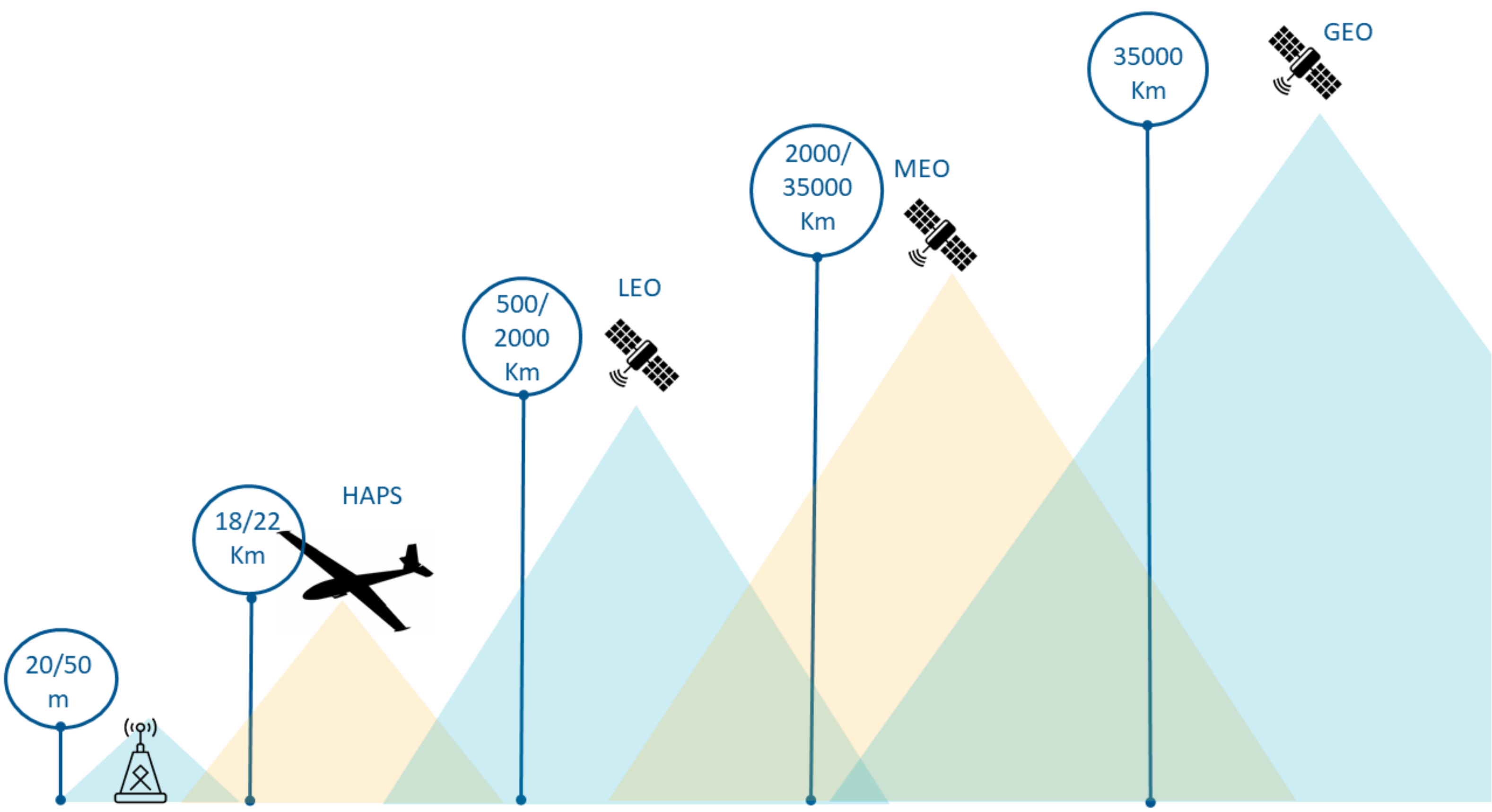
And Industry Organizations:

Landscape

A long-standing objective for mobile operators worldwide is to realise universal cellular coverage to reduce, and ultimately remove, 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). The following figure shows some potential solutions and their operating altitudes.



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.

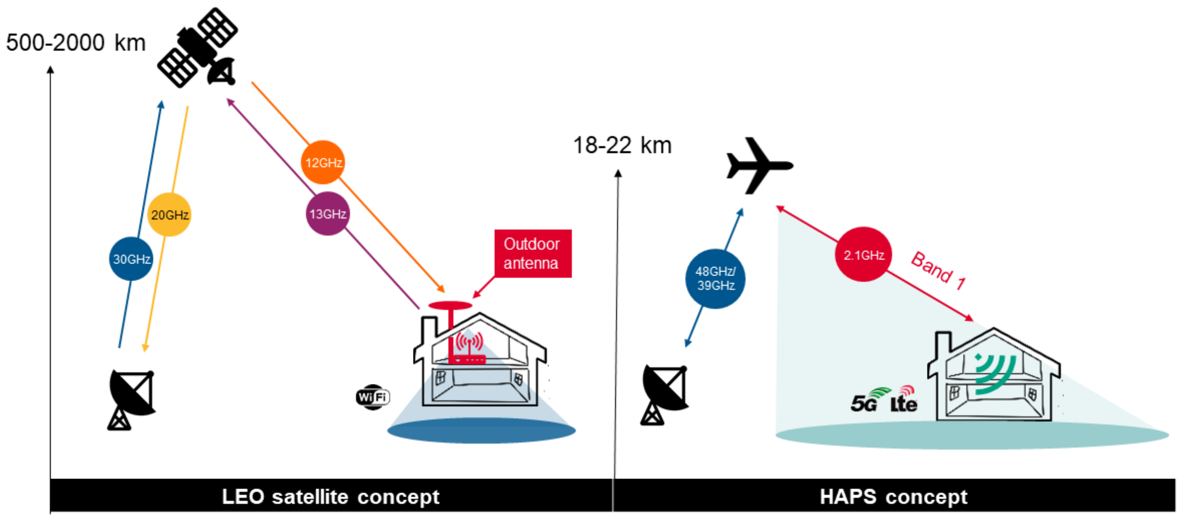
Low and Medium Earth Orbits (LEO and MEO)

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 LEO satellite 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)

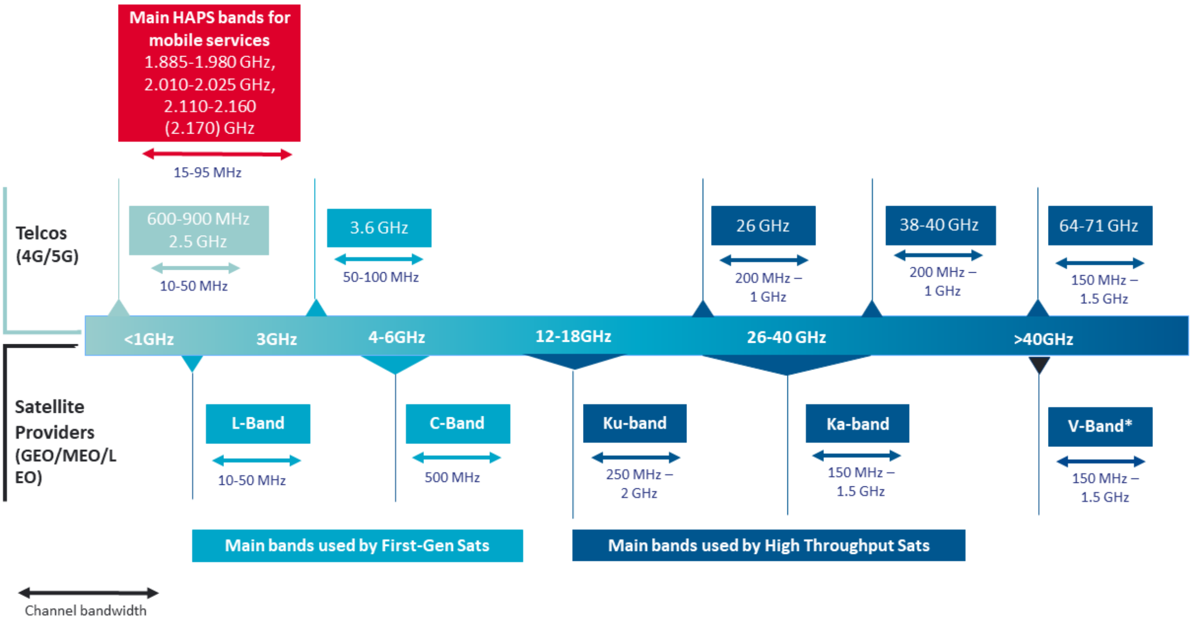
Unlike satellites, high altitude systems are aircraft that fly or float in the stratosphere, typically at altitudes of around 20km. They could be high-altitude free-floating balloons, dirigibles, or powered fixed-wing aircraft that use either solar power or an on-board energy source. All systems are 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, platform 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. On the other hand, HAPS benefits from a lower distance from the Earth which allows the provision of 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. HAPS capacity is flexible and can either be distributed to a wide area to provide blanket coverage or be focused on smaller areas of interest as needed.

HAPS can support the existing network infrastructure, potentially enabling the faster deployment of connectivity at lower cost in some situations. HAPS 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. The use of liquid hydrogen as a fuel also has potential environmental benefits.

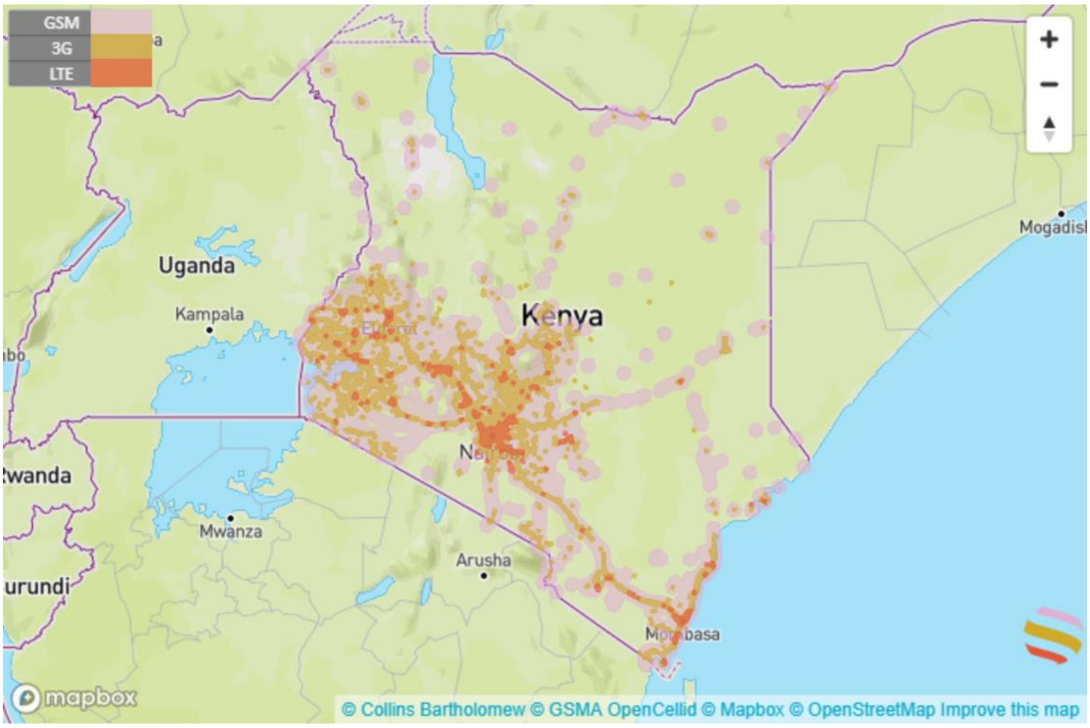
HAPS can support a variety of use cases for both developed and developing markets, including:

- 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
- Extended coverage over the sea

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, https://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[4]. An affordable internet connection provides education, access to

[4] 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

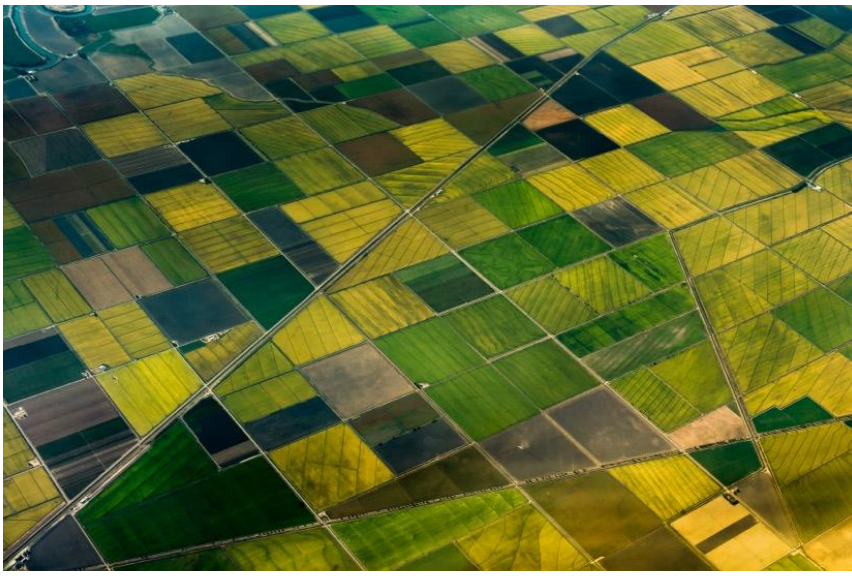
valuable information, various services, and the opportunity for businesses to interact with buyers and sellers globally.

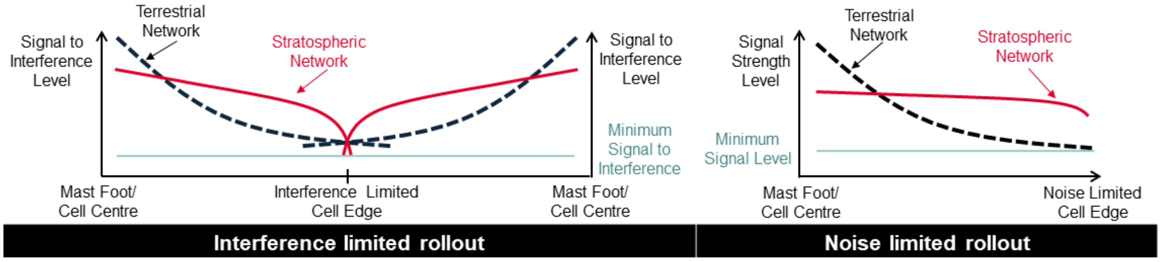
Deploying conventional wireless access network infrastructure in such locations is a challenge for the operators due to lower population density, terrain or lack of power and telecommunication infrastructure.

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), which is typical for a rural scenario.



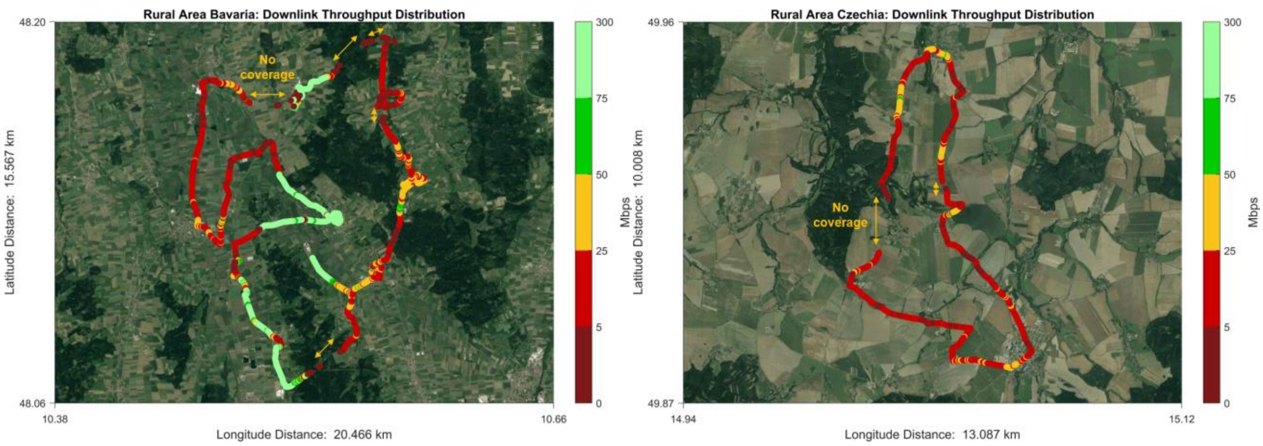


Further, network economics and planning constraints can make it challenging to cover rural areas with terrestrial networks. As many people experience while travelling via train, car or bus, there can be frequent connectivity interruptions due to patchy coverage. However, commuters and other travellers, 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. Different operators may have different site locations, and therefore non-identical coverage footprints, but any 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.

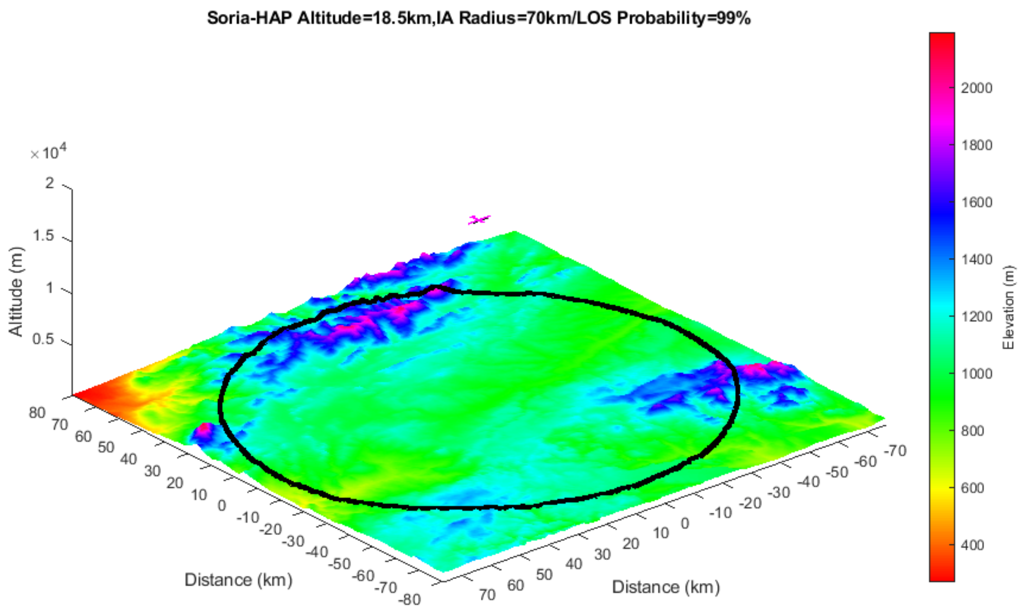
The pictures below illustrate the performance of a commercial network along randomly-chosen routes in a rural area in Czechia and Bavaria, Germany. White spots with no coverage were present in 8% and 10% of the route, respectively. In addition, there were villages with very low throughput or even no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



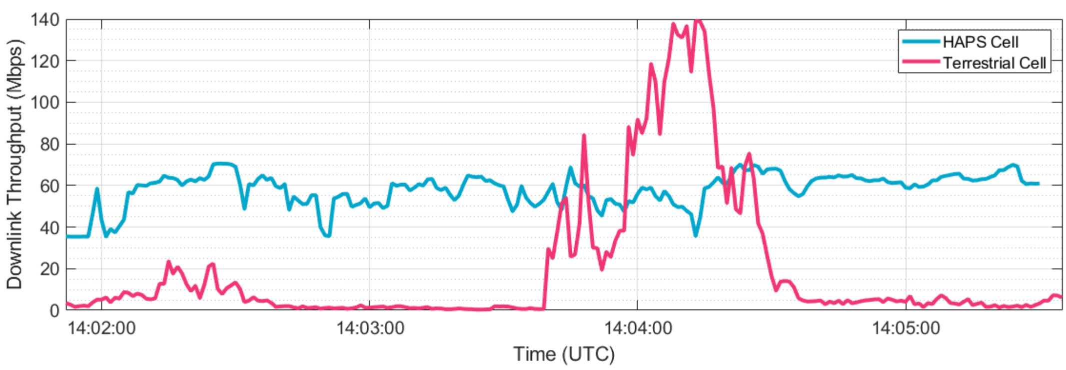
A key advantage of HAPS is the favourable radio propagation conditions afforded by the aircraft’s operational altitude, thereby allowing a high probability of line-of-sight with the terrestrial end-user devices. This is still true, even in the presence of terrain obstacles, which may otherwise adversely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

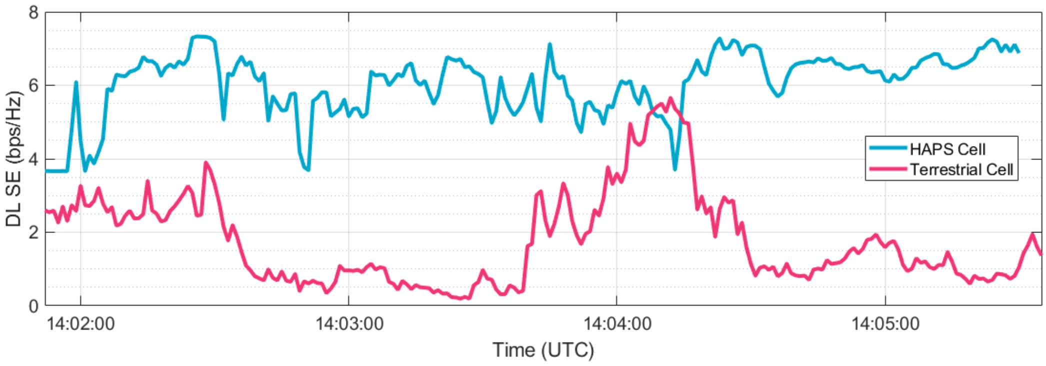
The following picture shows coverage simulation for the Soria region in Spain, which could be served by single HAP and would provide line of sight connectivity for 99% of the served area.



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 significantly depending on distance from the 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) 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, causing it to be more affected by terrain obstacles. This band could be fully utilised by HAPS, in rural areas (due to its 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 could also 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 could be ready in an airport, and in case of emergency, the platform can be quickly 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 in 2017 and 2019 respectively[5].

[5] 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. As well as enabling 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 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, including support for network slicing.

HAPS could also support V2X, or vehicle to everything (infrastructure, another vehicle, network, device, and pedestrian), communications[6] To 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.

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

Temporary coverage for events and tourist hotspots

Big events (e.g. 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 terrains, 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, such as Vasa race (Vasaloppet) or 220 km long extreme race Nordenskiöldsloppet in Lapland.

The main advantage of HAPS for this use case is ubiquitous coverage, which can't be achieved by any other technology in such difficult terrains. 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 the 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 (FWA)

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 (FWA) 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[7].

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[8].

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 due to the coverage being projected from above, rather than from the ground. HAPS enables all UAM and UAV applications to be served by a well-defined cell footprint and be free from terrestrial obstructions, allowing for continuous coverage throughout the entire flight mission.

[7] https://www.easa.europa.eu/what-is-uam
[8] 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[9]. 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

[9] 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 can also be applicable to ground communications in certain regions.[10]

Extended coverage over the sea

Offshore users lose connectivity as soon as they move toa few tens of kilometres from land or out of the line of sight of the base station. While large ships are equipped with SatCom terminals, a vast amount of small and medium size boats and vessels remain unconnected. Establishing connections for offshore users will improve not only the control of the vessels but also communication convenience for users.

HAPS can be used to establish an offshore user connection. Specifically, offshore users can directly access the LTE (or 5G) service link via HAPS from the onshore feeder gateway. Alternatively, it is possible to set up a CPE station on-board and use HAPS for cellular backhaul (CBH). Furthermore, connections can be forwarded to the terrestrial gateway via an inter-HAPS link or a HAPS-to-satellite link.

[10] 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 HAPS 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 HAPS for its own use to gain business advantage over competition. Service differentiators may be time to market and enhanced service coverage.

Shared

HAPS 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[11].

Neutral host

In a neutral host model, a private entity would deploy and operate HAPS 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.

[11] 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[12], UK).

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

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

Use Case Analysis

This section explores, by mean of examples, some of the use cases described in the previous section and performs an analysis of a given geography and the hence economic situation. The document does not provide an exhaustive analysis, but instead looks at different geographical regions which present some diversity. The intent of such analysis is to gather relevant information and infer some KPIs that represent the environment at its best. Where possible, a cost analysis is also provided for better understand what a reasonable benchmark would be. Both analysis on cost and performances should provide an understandable set of information for Platform Providers to refine their ongoing development to meet the needs and expectations of the market. Not all use cases described in the chapter Potential Use Cases have been fully analysed – rather only the primary needs have initially been considered.

Greenfield, Whitespots and Fixed Wireless Access Use Case

Given the close similarities of the use cases for greenfield, whitespots and fixed wireless access they are considered together. In most cases the technical KPIs are the same but with variation in coverage or type of service provided.

Greenfield - Denmark

MNOs seeking to extend their regional footprint are usually face a couple of strategic and operational challenges when entering a new market. Historically most of these new market moves went hand in hand with time and cost intensive M&A (Merger & Acquisitions) activities. In this scenario the MNOs take over existing terrestrial sites as well as existing whitespots and will have to come up with a new roll out plan to reach a desired coverage.

A second option - which was recently seen in the German market with 1&1 as a new player - is to extend the regional footprint by simply building new sites and renting existing sites from competitors in the market. Though this allows a tailored coverage scenario, a couple of disadvantages occur out of this approach, such as MNOs sometimes having to deal with long permission processes for building new sites (e.g., power connection) or facing the challenge of securing local contractor resources while at the same time having to meet coverage obligations from regulatory authorities.

In the following section, HAPS as a new approach for such a greenfield scenario will be introduced by taking the example of an MNO seeking to enter Denmark as a new player.

General Market Description

Denmark is considered a highly developed market in terms of digitization. In 2021 Denmark was ranked fourth in the IMD World Digital Competitiveness Ranking[13]. Though approximately 99% of the households have today access to 4G services the geographic coverage has still quite some upside potential. In addition, the demand for future smart applications will require higher capacities

[13] https://www.imd.org/globalassets/wcc/docs/release-2021/digital_2021.pdf

associated with 5G. The 5G service will have to be available not only in households but also on highways and remote locations such as farms[14].

Lying between the North Sea and the Baltic Sea Denmark has 483 islands of which roughly 80 can be considered as populated. The average height of 30m above sea level makes Denmark a comparatively flat country with a total area of 42.933 km^2. As of today, Denmark has a population of roughly 5.850.000 inhabitants which results in an average population density of approx. 136 inhabitants / km^2.

Methodology description

To evaluate HAPS as a potential alternative to enter a new market it is essential to understand economical as well as technical boundary conditions for this new solution. Therefore, on the economical side a bottom up approach is used that estimates costs for a pure terrestrial roll out. By doing so MNOs give a price indication for HAPS. With this benchmark, vendors are given thresholds they need to take into consideration when constructing and producing HAPS. For obtaining such a cost benchmark, average costs for single sites were assumed and multiplied with the number of required sites to reach the desired market coverage. The correct interpretation of the calculated costs will only be possible if the technical basis is also described. For this reason, the main technical and service related KPIs are described in Table 4.

Use case analysis

Denmark serves as a practical greenfield use case, due to its high potential in geographic coverage. Considering population and area size it was estimated that roughly 3000 sites would be needed for a market share of 25% in 2025.

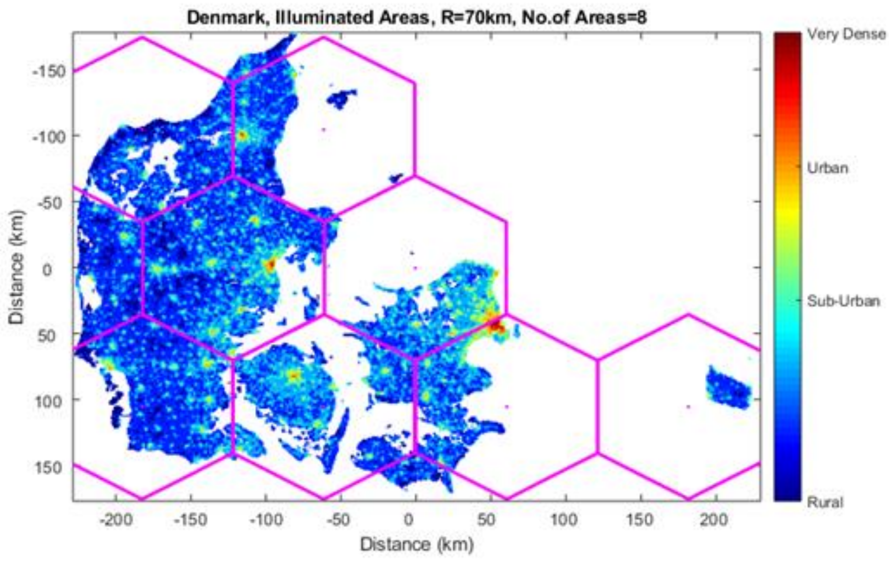


Figure 1: Denmark Population Density and HAPS Coverage

Note: Figure 1 is illustrating only one potential distribution of HAPS cells. In this case a radius of 70km per cell was assumed

[14] WIK-Consult, Study for Danish Energy Agency

In dense areas it is assumed that HAPS will not be able to compete with existing terrestrial sites. This result in the total number of sites covered by HAPS to decreases to 1810 for a likely case scenario. The structure of the terrestrial network in this case would then be:

Rural areas – Masts: 1735

Populated areas – Rooftops: 70

Dense areas – Rooftops: 5

Assuming a worst-case scenario that might emerge from deductions due to technical reasons, such as antenna capacity or higher number of reseller sites acquired the number of terrestrial sites substituted by HAPS could even further be reduced to 1261. The structure of the terrestrial network in this case would then be:

Rural areas – Masts: 1215

Populated areas – Rooftops: 46

Dense areas – Rooftops: 0

As a benchmark for a potential HAPS solution cost, a pure terrestrial roll-out cost analysis has been calculated. The cost prediction structure for CAPEX, given in Table 1 and Table 2, was calculated using the above input assumptions for masts and rooftops. The OPEX cost assumptions are given for the operating time of 8 years and are listed in Table 3.

CAPEX costs:

Table 1: CAPEX considerations for Masts

Mast / Steel / Buildings
Power Connection
Foundation / Earth works
Street for construction work
Acquisition & Planning
System Technology / Meters etc.
Antenna
Others

Table 2: CAPEX considerations for Rooftops

Steel
Roof work / cable routes
Electrical Installations
Crane
Acquisition & Planning
Technical room / Safety Engineering
Antenna
Others

Table 3: OPEX considerations

OPEX costs – 8 years:
Rental
Maintenance
Energy
Others

The two analysed scenarios yielded the costs of **~ 530M € in the likely case** and **~ 300M € in the worst case**. It should be noted that in addition to the reduction of the number of sites, the worst-case scenario assumes a cost reduction of 20% for terrestrial sites, which at the moment seems highly unrealistic due to continuously increasing costs for materials (e.g., steel) and contractor resources.

Technical KPIs

This table below contains the technical KPIs used in the analysis for all the greenfield scenarios:

Table 4: Technical KPIs Based on forecast 20GB/month in 2025 for Denmark

Information	Content unit	Input
Service type		5G
Service availability		24/7 - 365 days
Coverage type		Indoor & Outdoor
Total Area of Coverage	Area in km^2	43000
==> *Rural coverage*	Area in km^2	38743
==> *Urban coverage*	Area in km^2	3956
==> *Dense urban coverage*	Area in km^2	301
Population density	[pop/km^2]	
==> *Rural density*	[pop/km^2]	54
==> *Urban density*	[pop/km^2]	691
==> *Dense urban density*	[pop/km^2]	3435
Total potential customers distribution	number	5860000
==> *Rural customers*		2092000
==> *Urban customers*		2734000

==> *Dense urban customers*		1034000
Target market reach	%	25
Total target customers	number	1465000
==> *Rural target customers*		523000
==> *Urban target customers*		683500
==> *Dense urban target customers*		258500
Indicator of technical feasibility for	%	
==> *Rural coverage*		100
==> *Urban coverage*		40
==> *Dense urban coverage*		3
Average data consumption per customer		
==> *Rural customers*	GB	32
==> *Urban customers*	GB	17
==> *Dense urban customers*	GB	0.5
Desired Latency	ms	<50

*Based on forecast 20GB/month in 2025

Conclusions

As for every new technology, a thorough economic viability analysis must be done. The presented use case analysis is giving the ballpark cost indication to platform producers. Two scenarios – likely and worst – were analysed to have a more comprehensive cost overview. Irrespective of the technical solution, the customer's willingness to pay must be reflected at a later stage in a deeper market analysis to understand constraints that are purely driven by the law of supply and demand. In that context, further attention also needs to be paid to the business model, e.g. MNOs don't necessarily have to be the owner and could just pay a fee for renting the drones. To go even further a deeper analysis could consider HAPS as multi-use case service. MNOs could offer the platform as a backup service to governments for the purpose of network recovery in case of an emergency and generate further revenues. As many assumptions about stratospheric platform capabilities were made, a more detailed analysis between MNOs and platform suppliers must be carried out to identify economic and technical potential. With associated costs between 300-500 M € for a terrestrial roll-out, HAPS suppliers are given thresholds for their solutions.

Greenfield – Liberia

In order to shed a complementary light on the economic and technical conditions that may be met in Greenfield areas, an illustrative case of large-scale area with low user income is given. In this scenario, the focus is on a rural area with very low network coverage (around 10% of the population) where traditional terrestrial coverage extension is generally considered as not viable, due the high costs of deploying regular mobile cells to reach a low ARPU, deep rural population, scattered over a large area. Moreover, this scenario investigates how an MNO with an existing footprint in the more urban and profitable areas of the example country may extend its existing coverage with the help of HAPS platforms.

General market description

Over the 5-million population in Liberia, about 3.4M inhabitants are under a 2G network coverage[15], which still leaves a quarter of the population without any coverage. In addition, Liberia is heavily marked by rural habitat, with less than 6% of the country surface with a population density above 100 inhabitants/km^2. In contrast, more than 80% of the country can be considered as deep rural, i.e., with very low population densities, around 1-2 inhabitants per km^2 and below.

Another structuring element for this market is the very low ARPU, compared to the more urban areas of Liberia and Africa in general. As an example, in 2020 the average ARPU in the African Orange footprint was around 2.6€/user/month[16], the regions of interest in this use case would yield significantly lower revenues, with ARPUs below 1€, even down to 0.60€ per user per month for the specific area to cover.

Methodology description

This case focuses on a single spot area of 15000 km^2, roughly representing a surface of interest located in northwest Liberia, for which around 160000 inhabitants (i.e., 90% of the considered population) are not yet covered by any 2G+ network. Figure 2: Population distribution in Liberia and location of the specific area of interestFigure 2 illustrates, along with the general country population distribution, the location of this single spot area. The objective is to deploy an extension coverage, either of terrestrial nature, or supported by HAPS platforms, in order to cover up to 100% of the considered population. Therefore, the expenditure and operational costs (CapEx/OpEx) for a terrestrial extension of base stations have been roughly estimated and extrapolated to cover this target population. These CapEx/OpEx for the terrestrial coverage extension have been converted into a monthly cost per user, assuming a 10-year financial study and subsequent CapEx amortization. This way, costs should more easily be compared with user revenues, on a monthly basis for the sake of simplicity. Moreover, an estimation of the cost of several HAPS solutions to cover the same amount of surface and inhabitants allowed us to outline a range of potential HAPS monthly costs per user[17]. On this basis, Figure 3 illustrates how the terrestrial and aerial potential coverage extensions would compare with the typical ARPU in this area.

[15] https://www.mobilecoveragemaps.com/map_lr#8/6.247/-9.409

[16] *Source Orange 2021 https://www.orange.com/sites/orangecom/files/2021-07/Africa%20Day%20Presentation%20vDef.pdf*

[17] *Note that this estimation for platforms still in development is highly subject to change and therefore provided as an illustrative indication of the current cost trends. The intention is to provide a reference to easily understand how the HAPS cost structures should evolve to achieve minimum scenario profitability.*

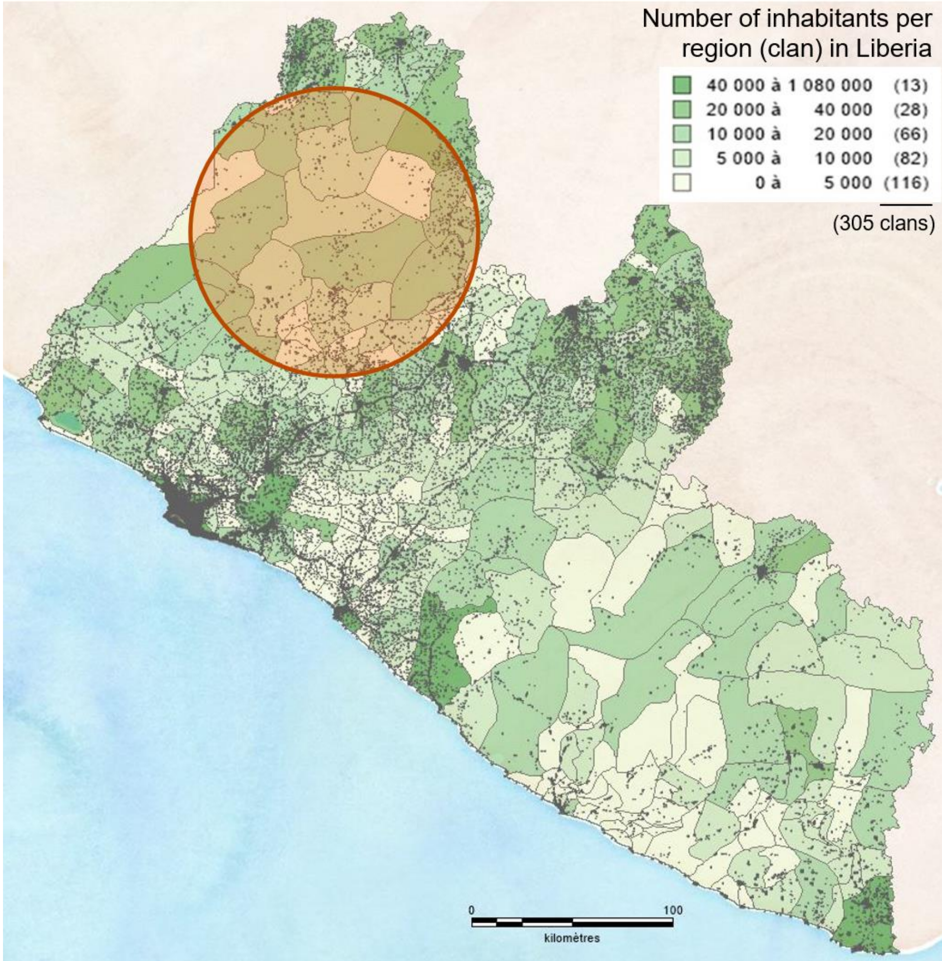


Figure 2: Population distribution in Liberia and location of the specific area of interest

Use case analysis

Figure 3 shows that as expected, a terrestrial-based coverage extension would quickly become economically unviable since the subsequent monthly cost per user would steeply rise above the estimated ARPU for this area. For a HAP-based coverage extension, a reverse trend is expected, i.e. a cost per user per month which is initially high and which decreases as the percentage of additional population covered increases. In this regard, the blue dotted curve gives an estimation of how this cost evolves. Moreover, this illustrative curve intersects with the average ARPU observed in the considered area when the maximum percentage of additional population is reached. It can therefore be considered as a threshold below which this scenario would have a chance to become profitable.

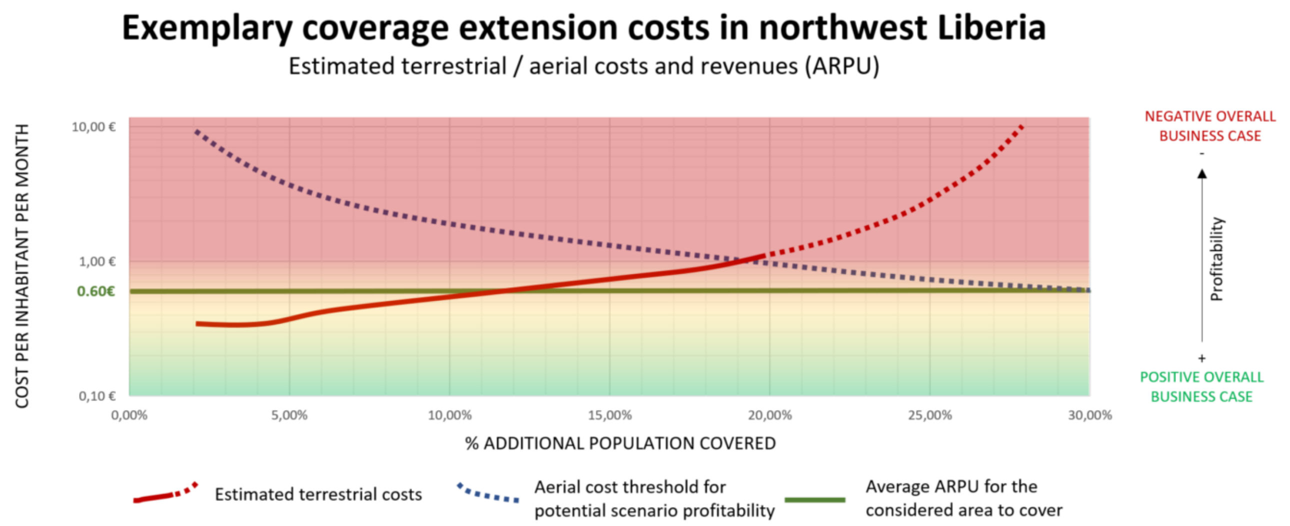


Figure 3: Estimated cost of deploying a terrestrial coverage extension in the considered northwest area of Liberia, along with a HAP-based cost threshold for potential scenario profitability. Note: logarithmic axis for the cost per inhabitant per month.

Technical KPIs

Table 5: Technical KPIs for use case in Liberia

Information	Content unit	Input
Service type		2G-LTE
Service availability		24/7 - 365 days
Coverage type		Indoor & Outdoor
Total Area of Coverage	Area in Km2	
==> *Rural coverage*	Area in Km2	15000
==> Rural density	[pop/Km2]	
==> *Rural density*	[pop/Km2]	50
Total potential customers distribution	number	
==> *Rural customers*		160000
Target market reach	%	30.00%
Total target customers	number	
==> *Rural target customers*		48000

Indicator of technical feasability for	%	
==> *Rural coverage*		100
Average data consumption per customer		
==> *Rural customers*	kb/s	30 kb/s
Desired Latency	ms	<50ms

Conclusion

Although this deep rural Greenfield scenario would be economically challenging for any coverage extension, either terrestrial or aerial, it is hoped that HAPS manufacturers may successfully lower their platform costs below the cost threshold depicted by Figure 3. However, although the capacity demand could be judged as relatively limited in comparison to other scenarios, it must also be highlighted that this case also incurs technical challenges. In particular, HAPS-based coverage may overlap with the existing terrestrial footprint. In this regard, Figure 4 shows that in a hypothetical 500-cell HAPS infrastructure deployment, 308 cells (in blue) would yield a non-null user traffic[18], and among those 87 (in darker blue) would overlap with existing terrestrial footprint. Since it is estimated that these overlapping cells would also contain almost a third of the uncovered population, it is particularly important that HAPS deployments allow an efficient coexistence between the terrestrial and aerial footprints.

[18] For the sake of simplicity, we only considered user traffic from households. However, more elaborate cases may also take into account user mobility patterns (for service continuity). In this case, all 500 cells would likely yield a non-null user traffic at some time. In any case, the concluding remarks about user traffic heterogeneity and the need to ensure coexistence between terrestrial and HAPS-based cells still strongly hold.

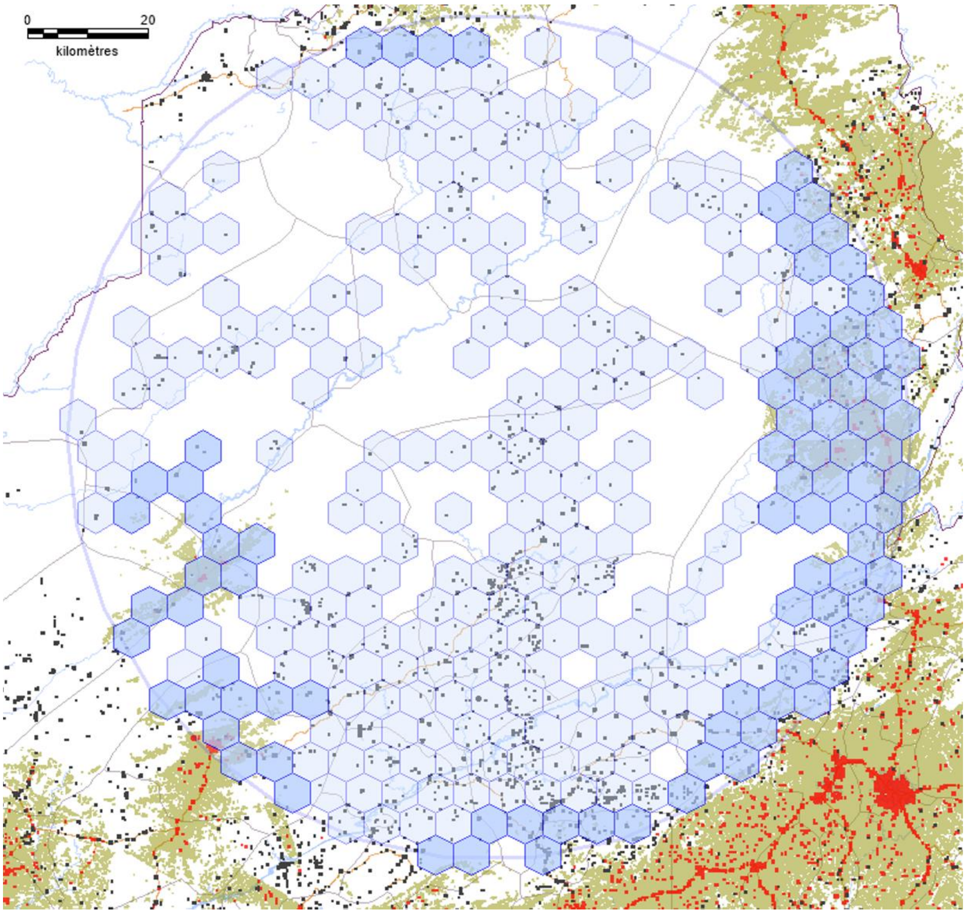


Figure 4: In an exemplary 500-cell HAPS partition, 87 cells (dark blue) would overlap with the terrestrial network coverage. Note that the black dots represent the uncovered population in the considered northwest area of Liberia.

Greenfield – Mexico

To explore the commercial viability of a HAPS-based solution for Greenfield coverage and to understand better the key economic drivers of the business case for a HAPS deployment, a study was conducted in 2020.

A key goal for HAPS-based solutions for Greenfield coverage is to fill gaps in economically efficient mobile network coverage.

In order for HAPS to be an effective solution in delivering mobile network coverage to a given target area of coverage, two basic criteria need to be met which are that:

- The cost of covering an area with HAPS is less than the cost of covering such area with terrestrial tower technology.
- The marginal revenues expected to be derived from the area are higher than the cost of coverage of such area with HAPS.

The above criteria are based on the underlying assumptions that terrestrial tower technology where available will support higher density solutions than HAPS, and that HAPS in turn will support higher density solutions vs. alternative space-based technologies such as satellite.

The study focused on defining the appropriate situations where HAPS can play a commercially viable role in expanding mobile network coverage through analysis of a specific market - Mexico.

General Market Description

Mexico was chosen as a good target for this study. It has a population of 126 million, with per capita GDP of approximately US$10,000 which is close to the median among countries worldwide. It has a sizeable underserved population - approximately 37% of the population does not have mobile internet access, and 21% of the population lives in rural areas.

Based on the analysis conducted as part of the study, it is estimated that approximately 13% of the population lives in an area that is either unserved (no access) or underserved (limited access) to a mobile network. This group was identified as a primary target for a HAPS-based solution.

Methodology Description and Technical KPIs

The study analyzed the Mexican market on a state-by-state basis to assess those states and municipalities that have unserved or underserved areas that may be suitable for mobile network coverage via a HAPS-based system and compared revenue opportunities vis-à-vis the estimated cost of deploying a network.

Mobile network subscribers that access the HAPS-based mobile network were assumed to pay $3/GB and use 2 GB per month.

Table 6: Technical KPI for Greenfield case in Mexico

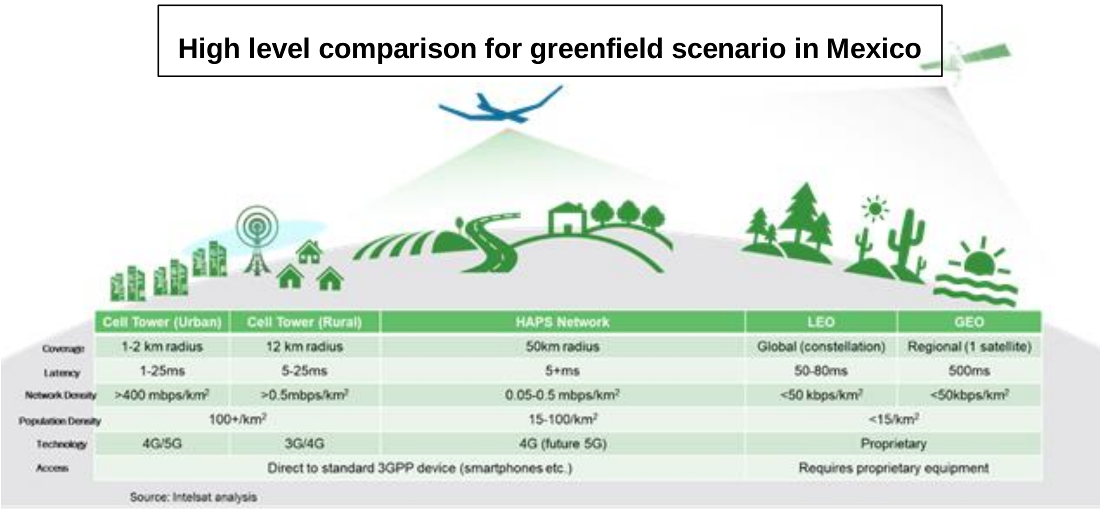
Information	Content Unit	Input
Radius for single HAPS coverage area	Km	50
BS Capacity (uplink and downlink)	Mbps	1,000
BS per Aircraft	Number	1
Simultaneous Users per BS	Number	>1,000

Conclusions

The key findings of the study were that:

- There is a significant market opportunity in Mexico to provide mobile networking connectivity direct to end-user devices in the targeted unserved and underserved regions.
- There is some confidence that HAPS could technically and economically fill a complementary role to support expansion of the reach of mobile network operator coverage beyond existing terrestrial tower coverage into rural areas.
- At the same time there is sensitivity in the cost of deploying HAPS-based mobile networks and thus HAPS on its own will not entirely address a given country’s digital divide problem.

- For the Mexico market and based on the available data and assumptions used in the study, the appropriate target for HAPS is estimated to be those areas with population density between 15-100 people/km^2 and between 0.05-0.5 mbps/km^2 in required network density. This range will be different by country and within Mexico it may also vary depending on parameters such as the HAPS mobile network design and type and cost of the aircraft considered.
- While numerous cost drivers contribute to this sensitivity, the upfront cost of the HAPS aircraft and on-board payload are the largest drivers. HAPS aircraft with a lower cost base per unit are more likely to be commercially complementary to cell towers albeit lower cost typically relates to smaller sized aircraft which in turn means that innovation is required in developing efficient payload technology to enable sufficient network performance.
- Areas with very low population density (less than 15 people/km^2) are unlikely to deliver sufficient revenue to support a HAPS-based network. Such areas may be appropriate to support via a satellite-based solution, or to be subsidized for a HAPS solution via some form of funding.



	Cell Tower (Urban)	Cell Tower (Rural)	HAPS Network	LEO	GEO
Coverage	1-2 km radius	12 km radius	50km radius	Global (constellation)	Regional (1 satellite)
Latency	1-25ms	5-25ms	5+ms	50-80ms	500ms
Network Density	>400 mbps/km^2	>0.5mbps/km^2	0.05-0.5 mbps/km^2	<50 kbps/km^2	<50kbps/km^2
Population Density	100+/km^2		15-100/km^2	<15/km^2	
Technology	4G/5G	3G/4G	4G (future 5G)	Proprietary	
Access	Direct to standard 3GPP device (smartphones etc.)			Requires proprietary equipment	

Source: Intelsat analysis

Figure 5: Positioning of HAPS Network Capabilities vs. Alternative Technologies

- At above 100 people/km^2 the economics are more likely to favor additional terrestrial tower buildout although this will be impacted by variables such as terrain, security, local regulations etc.

To put this range into perspective, approximately 47% of Mexico's municipalities have a population density profile between 15-100 people/km^2. These municipalities account for 24% of the population and 33% of the total area in Mexico. In contrast, municipalities with population density of less than 15 people/km^2 accounts for 57% of the area of Mexico.

Fixed Wireless Access (FWA) in rural areas – Europe

One potential use case for HAPS is linked to the provision of reasonable broadband capacity for Fixed Wireless Access (FWA) in remote areas where neither fibre/copper nor mobile networks are economically viable or are able to reach with sufficient capacity to provide a reasonable customer experience.

The application of this use case may be thought mostly in remote regions for different continents. In order to set-up a proper benchmark for such a use case, a deep-rural area of Europe within

Spain was selected. While it is recognized that it may not be the most interesting area for HAPS due to quite extended mobile and fibre networks, it can be used as blueprint for extension to other areas, under the assumption that the technical challenges and the methodology for the analysis may be of similar nature.

General market description

A specific low population density area within Northwest part of Spain is presented for blueprint analysis. The area comprises around 31400km2 and roughly 787k inhabitants, giving an average population density of ~25 inhabitants per km2 and with an average of 2.5 inhabitants per household. The population is mostly concentrated in urban areas where there is already sufficient 4G/5G and fibre coverage, which are excluded from the analysis.

The focus of the analysis lies then on the areas having 4G coverage with a maximum of 10MHz of spectrum assigned to it. It is important to note that fibre coverage may reach those areas but, for simplicity and with the main objective of setting this as a blueprint scenario, this is not taken into consideration. Based on this, the target area includes a total of 1,007 municipalities (67% of the total number of municipalities in the area) which covers 124000 inhabitants (16% of total) and implies ~50000 target households.

The following picture shows the area (mostly comprising Soria and La Rioja provinces but also including partially two other provinces with larger population density, Navarra and Alava). This corresponds to approximately a 100km radius circle, simulating the potential total coverage radius of a single HAP, as referenced by some platform providers. It must be noted that this is just an assumption for the sake of the analysis, based on references of current design targets given by platform providers.

The green/purple coloured areas are excluded from the analysis as counting with sufficient 4G coverage[19] (more than 10MHz) and target areas are outside of these. Target municipalities having broadband mobile service of maximum 10MHz LTE are consolidated in hexagonal cells of specific radius to identify coverage targets (actual radius will be dependent on the capacity targets), shown in blue colour in the picture.

[19] https://www.movistar.es/particulares/coberturas/movil/

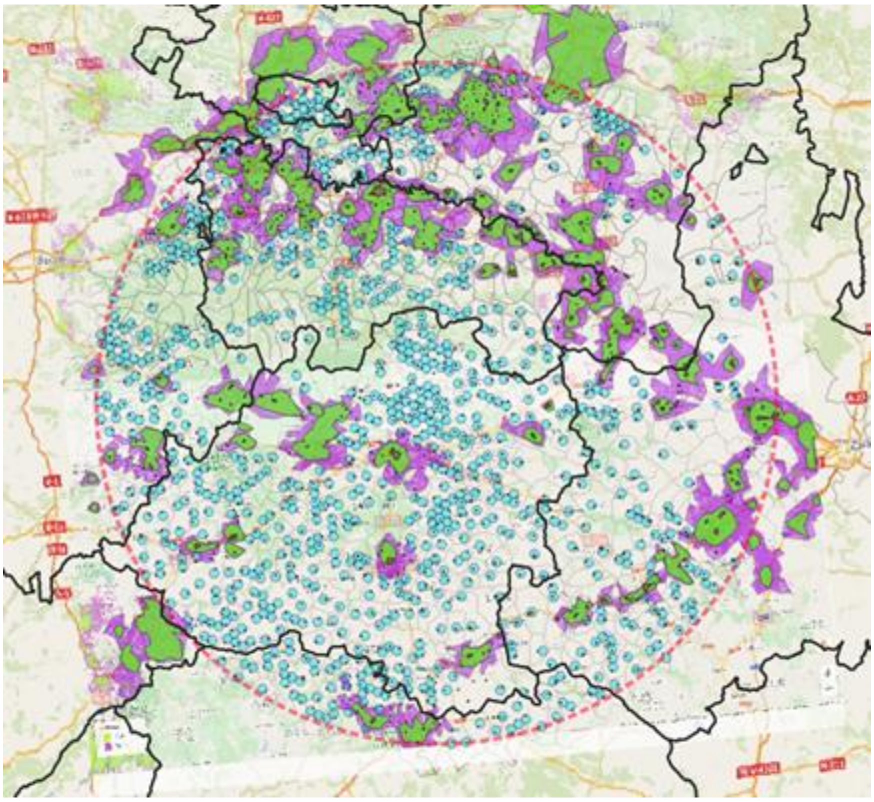


Figure 6: Coverage in the rural regions of Soria and La Rioja in Spain

Methodology description

Fixed Wireless Access services could be provided by either extending the terrestrial network (in this case based on C-Band 5G solutions) or by providing a similar service from the air based on one or more HAP solutions.

In terms of user experience, either the terrestrial network or the HAP solution shall provide a service quality objective of 100 Mbit/s for DL and 5 Mbit/s for UL peak user throughput with a reference of minimum committed 10Mbit/s DL throughput at worst-case busy hour.

For the terrestrial network,

- a de-facto rollout of one C-band site location per municipality is required, while in some cases, population density and target service quality set mean that more than one site would be needed to enable sufficient quality/capacity.
- Propagation model is based on SUI (Stanford University Interim) model for 3600MHz and considering external antenna installation at connected household with 10dBi gain.
- 100MHz of spectrum at C-band with a 75:25 DL:UL TDD split is considered.
- Terrestrial macro-sites are considered tri-sector with 4G and 5G technologies on it (while only 5G C-band spectrum is considered in the capacity analysis)
- No constraints on terrestrial site location are considered

HAP solutions shall be capable of providing similar performance in terms of user experience and capacity to target households as the terrestrial network extension to allow for an apples-to-apples comparison.

Having solutions for both terrestrial network (available from Operator) and for HAP solution (to be provided by HAP provider), a techno-economical comparison of both can be performed to define the suitability of HAP solutions for these kinds of applications. The comparison is made both between terrestrial and HAP solutions and against a specific business case which would provide positive results from Operator perspective, considering different scenarios of commercial success (% of total number of target households contracting to the service)

Use case analysis and preliminary high level conclusions

Similar to the Liberia case, extension of terrestrial network to provide FWA services is quite efficient for higher populated areas but becomes less and less efficient when moving onto more sparsely populated areas. The analysis looks to provide a reference of up to which point HAP solutions could be used to cover these extensions, depending on its associated costs and technical performance. Scenario-specific ARPU figures will determine the viability of a business case either for terrestrial, HAP or both, being quite characteristic of the region under analysis. Overall feasibility in terms of a positive business case also needs to be considered in parallel to the pure HAP vs. terrestrial solution comparability analysis.

Additionally, differences between terrestrial and HAP solutions may also arise dependent on assumptions of commercial adoption of the FWA services, so that an analysis for different adoption levels is seen as a basic need in the scenario comparison.

Technical KPIs

Table 7: Technical KPIs for the use case of Fixed Wireless Access in rural Spain

Information	Content unit	Input
Service type		5G
Service availability		24/7 - 365 days. Same availability as terrestrial network
Coverage type		Household – external antenna considered
Total Area of Coverage	Area in km^2	31400
==> *Target municipalities*	Number	1007
==> *Non-target municipalities*	Number	504
Population (target customers)	[pop]	787000
==> *Target municipalities*	[pop]	124000 (50k households)

==> Non-target municipalities	[pop]	663000
Target market reach	%	Analysis to be done for different values (25%, 50%, 75% and 100%)
Target Customer Experience		
==> DL user throughput	Mbit/s	100
==> UL user throughput	Mbit/s	5
==> DL minimum BH user throughput	Mbit/s	10
Total solution Capacity	Gbit/s	Similar to equivalent terrestrial network to support use case
Coverage Solution	Gbit/s	Solution to coexist with existing terrestrial network shall be provided
Desired Latency	ms	<50ms (similar to terrestrial network)

(Further detailed geo-based information with distribution of target areas can be provided on request)

- A preliminary high-level analysis was carried out considering different commercial adoption figures in the target areas, and coverage radius for terrestrial (and HAP solution) from 1Km to higher than 3km, taking also into consideration zone-specific assumptions for the terrestrial deployment costs and customer ARPUs. Commercial service target costs were also derived to use a target for the business case feasibility. With the selected alternatives considered for site radius, required terrestrial sites were in the many hundreds range in all the cases.

Aside of these high-level considerations, some key relevant aspects were also identified which are linked to technical uncertainties in the HAP implementation, and these may need to be taken into account in any detailed scenario evaluation or comparability analysis:

- Important technical features of the HAP solution are used frequencies and bandwidth, as well as the provided antenna solution to null-out radiation in frequencies used (or planned to be used) by terrestrial network in specific target areas. Many scenarios will be brownfield, and as the target area contains urban areas with significant mobile network development, it is important that whatever HAP solution may be considered does not cause harmful interference to these existing terrestrial networks.
  Another relevant aspect identified in the scenarios is the non-uniform distribution of capacity within the overall radius for a single HAPS coverage area, where locations of few tens of inhabitants, mix with others much larger which may require asymmetric capacity distribution in the HAP design, to avoid capacity limitations in specific areas and ensure comparability and uniform service targets.

Additionally, a large coverage radius as the one considered in this example (100Km), whilst favoring the HAP use case by being able to integrate a larger number of potential users, also has some other implications in the scenario that may impact feasibility. Examples include, remote side low elevation angles and derived problems, extended beam footprints with increased interference, lower capacity per user or overall lower spectral efficiency per beam. All these influence the antenna /baseband design and have implications on the HAP power consumption, autonomy, etc. and also have a potential large impact on the case economics.

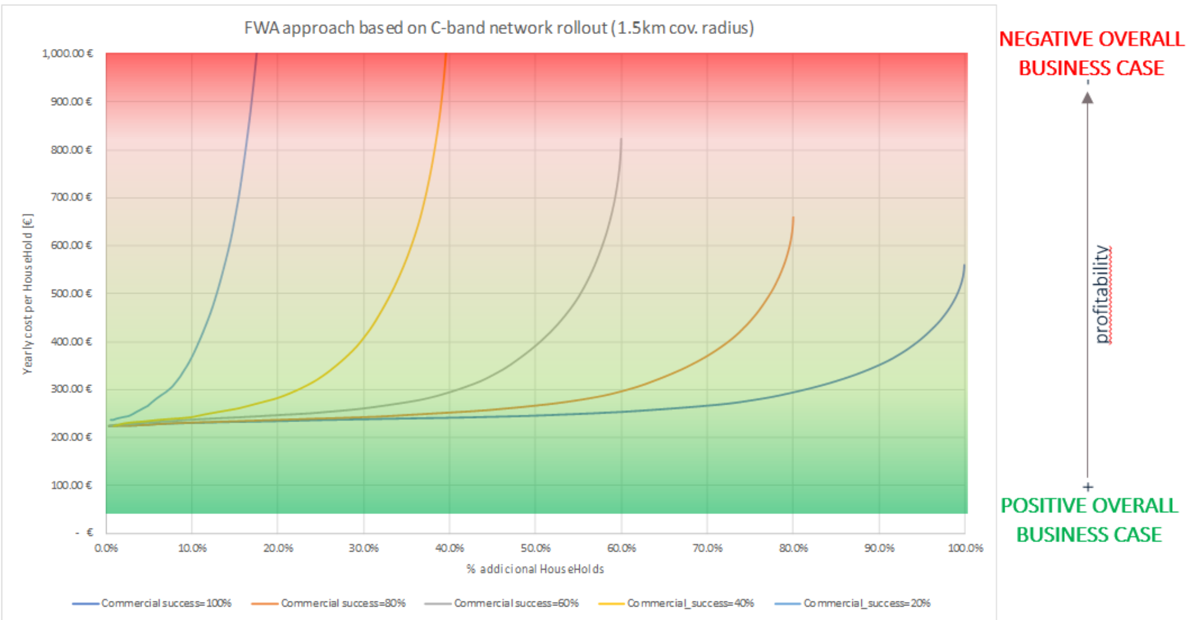


Figure 7: Estimated cost of deploying a terrestrial FWA in rural areas of Spain according to set CEX criteria

Whitespots – Japan

Use case analysis

As explained in the Potential Use Cases chapter, white spots are typical for areas such as the rural scenario, where it is difficult to deploy terrestrial base stations mainly as the result of terrain obstacles.

Normally, when attempting to provide communications to these areas, the deployment cost for terrestrial base stations would be high and new procurement of backhaul would be needed. Considering that most white spots are small and non-contiguous areas, it is assumed that it would typically require the large scale deployment of terrestrial base stations to cover them. This high deployment cost is thought to be the main reason why MNOs are hesitant to take measures to eliminate the white spots. In addition to that, due to the topographical characteristics of the area, the number of populations who use telecommunications tends to be small, making it less cost effective.

The main feature of HAPS is its ultra-wide coverage, which can cover many white spots by single HAPS. The intent of this analysis is to provide a proper benchmark for HAPS providers to understand what would be considered to be an acceptable cost.

The following figure shows a specific area of 100km in radius including white spots in Hokkaido prefecture, considered to be a rural scenario in Japan.

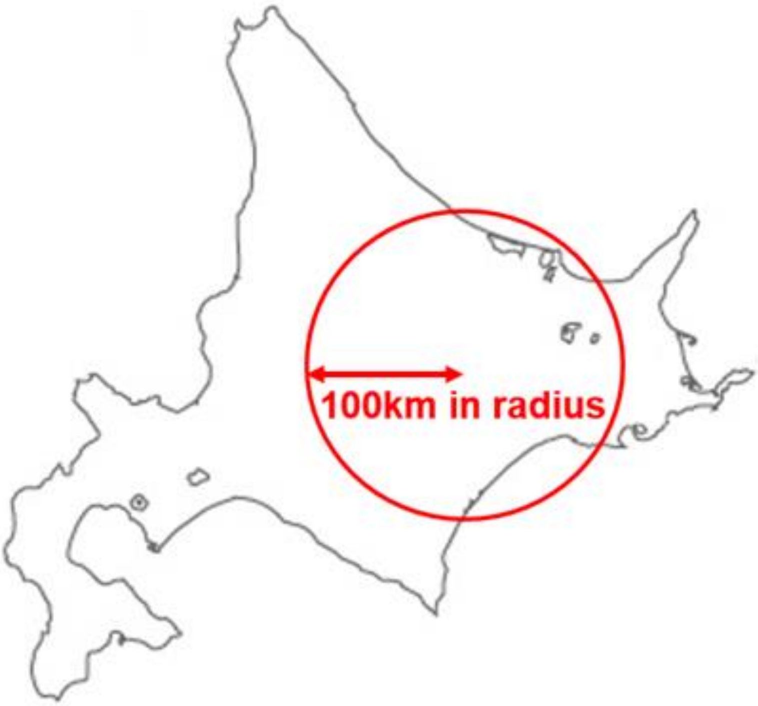


Figure 8: Rural area in Hokkaido, Japan.

Within this specific area, 54% of the area are white spots that are not currently covered by terrestrial base stations. It is estimated that about 1600 terrestrial base stations would be required to cover the area and that the total estimated cost would be around $445M (10-year TCO) assuming 10 years of operation. Divided by the number of target customers in this area, the cost per customer would be about $150 per month, which is higher than Japan's current monthly ARPU $40-70[20]. Therefore, it is economically unfeasible to reduce white spots only with terrestrial base stations.

[20] https://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2020/chapter-5.pdf#page=1

Technical KPIs

Table 8: Technical KPI for the rural area of Hokkaido.

Information	Content unit	input
Service type		LTE/5G
Service availability		24/7 - 365 days
Coverage type		Indoor & Outdoor
Total Area of Coverage	Area in Km2	29477
==> *Rural coverage*	Area in Km2	29477
==> *Urban coverage*	Area in Km2	N/A
==> *Dense urban coverage*	Area in Km2	N/A
Population density	[pop/Km2]	1～100
==> *Rural density*	[pop/Km2]	1～100
==> *Urban density*	[pop/Km2]	N/A
==> *Dense urban density*	[pop/Km2]	N/A
Total potential customers distribution	number	102409
==> *Rural customers*		102409
==> *Urban customers*		N/A
==> *Dense urban customers*		N/A
Target market reach	%	25
Total target customers	number	25602
==> *Rural target customers*		25602
==> *Urban target customers*		N/A
==> *Dense urban target customers*		N/A
Indicator of technical feasibility for	%	
==> *Rural coverage*		54
==> *Urban coverage*		N/A
==> *Dense urban coverage*		N/A

Average data consumption per customer	Kb/s	365Kb/s(DL), 150Kb/s(UL)
==> *Rural customers*	Kb/s	365Kb/s(DL), 150Kb/s(UL)
==> *Urban customers*	Gb/s	N/A
==> *Dense urban customers*	Gb/s	N/A
Desired Latency	ms	<10ms

Whitespots – German Alps

Use case analysis

Another example of an area, which could benefit from ubiquitous HAPS coverage is the Alps region. Terrain morphology limits the achieved service area per site while the population is dispersed over a wide area. Such places also have much higher build costs per site due to a lack of existing infrastructure.

Uninterrupted service could enable people to receive help faster in case of an emergency during their mountain visit. New 5G use cases such as autonomous driving will also require continuous connectivity plus low latency.

The mitigation of the white spots in the German Alps would require approximately 400 new sites to be built. In contrast, only 3-4 HAPS with a 70 km radius would provide basic mobile service in the same area. The total estimated cost of terrestrial roll-out per HAPS service area would be around 60M € assuming 8 years of operation. Therefore, an alternative economically feasible solution could be using HAPS.

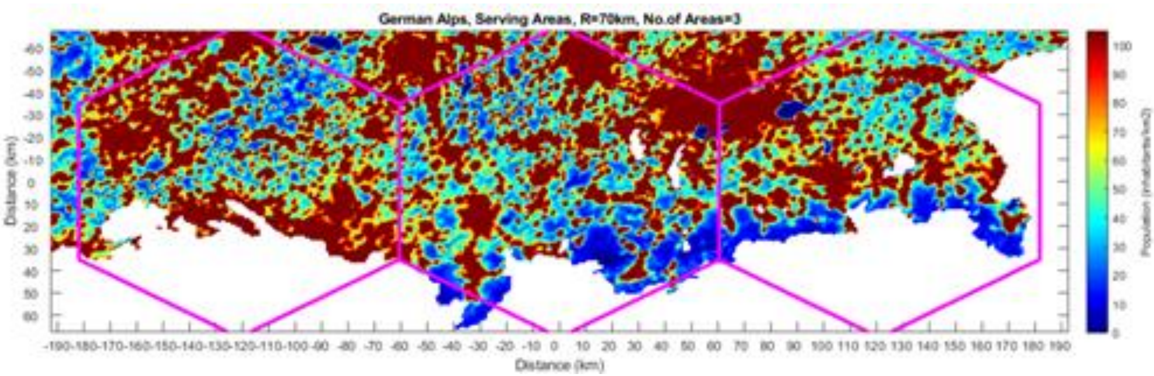


Figure 9: German Alps with depicted potential HAPS coverage areas and population density.

Technical KPIs

Below are listed the key KPIs that were considered during the analysis. Basic mobile service was assumed with 8 years of operation and a single HAPS operation radius of 70 km.

Table 9: Technical KPI for the rural area of German Alps

Information	Content unit	input
Service type		LTE/5G
Service availability		Partly 24/7 - 365 days
Coverage type		Indoor & Outdoor
Total Area of Coverage	Area in Km2	12731
==> *Rural coverage*	Area in Km2	12731 - patchy
Population density		
==> *Rural density*	[pop/Km2]	< 100
No. of new sites required per single	number	100
Radius for HAPS operation	Km	70
Total throughput per single HAPS	Gb/s	1
Total potential customers distribution	number	
==> *Rural customers*		25000
Target market reach	%	>40
Total target customers per single HAPS	number	
==> *Rural target customers*		25000
Average data consumption per customer		
==> *Rural customers*	kb/s	40
Desired Latency	ms	<50ms

Conclusions for both Whitespots use cases

For areas such as white spots, where it is economically unfeasible to cover using only terrestrial base stations, HAPS enables a cost-effective solution which can provide ultra-wide coverage. Furthermore, the deployment of HAPS will result in huge potential coverage from the air, which will enable services for existing mobile users as well as new services for IoT, urban air mobility, drones, etc. HAPS can also be used to replace the less economical existing terrestrial base stations, in a certain area. Considering that the white spot is usually in a rural area, MNOs can realise the co-existence between HAPS and terrestrial network by splitting its own frequencies. More detailed and comprehensive analysis should be performed according to the actual situation of the location where HAPS will be deployed.

Disaster Response

When natural disasters such as earthquakes and storms occur, HAPS will be easily and quickly dispatched to the affected areas from airfields that are on standby. Since HAPS flies in the stratosphere, it can provide communications to a wide area from far above thunderstorms, hurricanes, etc. and is not affected by them.

The primary difference with the other use cases is that the service is required for a limited period to substitute a currently unavailable service. So, the analysis of this use case is focusing more on aspects that are not directly related to the profitability since the main target is to provide a reasonable service for the safety of the affected citizens. The analysis looks at two areas that have been recently affected by earthquake and flood. In 2011, a tsunami affected the Iwate Prefecture in Japan for 2000km of coastline and inundate about 400 Km^2 in Iwate, Miyagi and Fukushima. Secondly, in 2021, Europe experienced a very devastating flood which impacted the Western part of Germany.

Methodology description

Disaster response, from a Telecom standpoint, includes a wide set of situations (natural, accidental, malicious) that lead to different service impacts, ranging from service degradation to complete service loss in the affected area. In the latter case, usually the telco operators exploit portable sites (“cells on wheels”) to quickly provide service in the most critical areas (e.g., the headquarters of the emergency teams), while repairing the affected infrastructure and restoring normal operations. However, different aspects need to be taken into account, such as:

- Area accessibility: affected areas might be difficult to reach;
- Timing: making a portable site available takes time;
- Workforce safety: operation in emergency area might expose personnel to danger.

There are two possible ways to connect to users in disaster area: (i) Cellular backhaul (CBH) where HAPS supports a backhaul between the core and the base station as an independent tunnel line and (ii) direct access (DA) where HAPS connects directly to the UEs. Connections via an inter-HAPS link or a HAPS-to-satellite link are also conceivable.

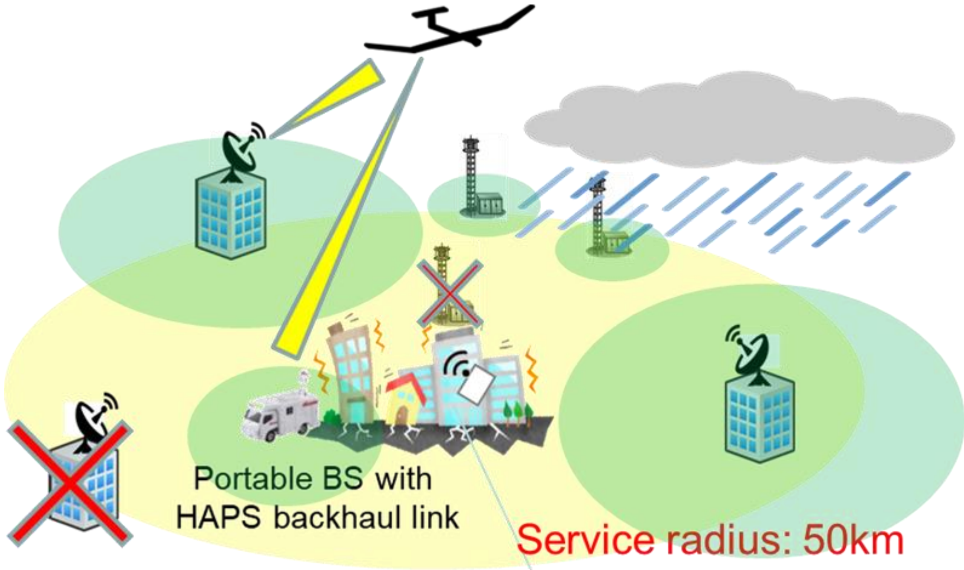
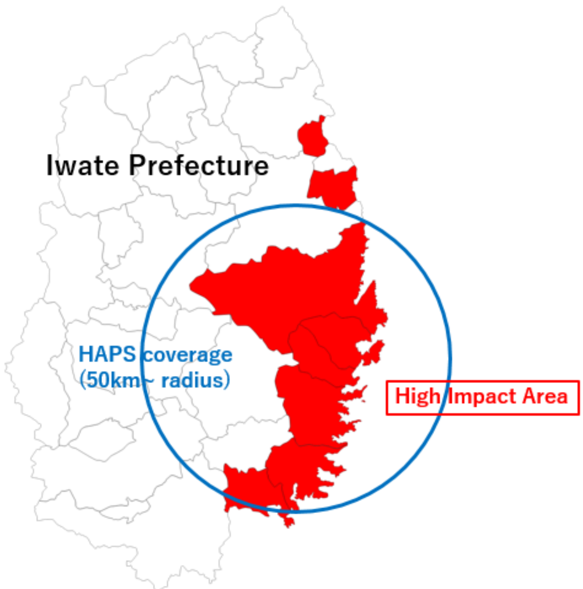


Figure 10: Disaster Response scenario

Use case analysis - Japan



An example of a use case for disaster response is the tsunami caused by the massive earthquake that hit Japan in 2011. Communication can be provided to the most damaged area of the tsunami (Iwate Prefecture coast), with one HAPS (radius of 50km~) instead of using more than 100 ground base stations. It is also possible to improve capacity by dispatching multiple HAPS.

One way to restore communications in a disaster is to dispatch HAPS to the disaster area to provide LTE or 5G user links and connect to terrestrial gateway stations via HAPS. In addition to the communication service, an additional visual transmission device can be installed to continuously check the conditions in the disaster area.

Technical KPIs

The analysis is focused on the option to provide a Cellular Backhaul only and the table below shows the considered KPI.

Table 10: Technical KPI for Disaster Response in Japan

Information	Content unit	input
Portable BS per single HAPS	Number	10
Users per portable BS	Number	100
Radius for single HAPS coverage area	Km	50
Throughput per portable BS	Gbps	1
Total throughput per single HAPS	Gbps	10

Profitability is not necessarily required in disaster relief scenarios. To save lives, users should be able to access the service for free.

In addition, from an economic point of view, it should be noted that the use of HAPS in disaster recovery situations may also be replicated to address other scenarios such as special events or tourist hotspots (as per the portable sites).

Use case analysis - Germany

Another use case analysis was done for nationwide disaster relief in Germany. In Germany, operators have a fleet of Cells on Wheels (CoW) to ensure the continuity of basic communication services.

Around 250 cells on wheels are prepared to be deployed in the affected area(s). CoWs are geographically dispersed to ensure a certain deployment time. Therefore, the total fleet can be in the range of hundreds of units, while their overall yearly utilization rate is typically very low. As such, they are reserving considerable CAPEX and OPEX resources.

One of the main HAPS advantages is the speed of deployment, which enables the network to be ready within hours, even in distant and temporary inaccessible locations. The drones could be located centrally and allocated dynamically to ensure connectivity in the affected areas. Another aspect to consider is the geographical footprint of HAPS in different configurations, either covering one large part of the country or distributed to different regions. However, supporting ground infrastructure would need to be deployed nationwide.

An example of potential HAPS deployment for disaster recovery was flooding in Germany in 2021. The western part of the country was affected by severe floods[21]. Due to the natural disaster scale, mobile networks were down, with the main reason being the lack of power supply for the base stations[22]. Rebuilding the network by MNOs was rather slow as many places remained

[21] https://www.theguardian.com/environment/2021/jul/16/climate-scientists-shocked-by-scale-of-floods-in-germany
[22] https://marketresearchtelecast.com/after-a-flood-disaster-the-holes-in-the-cellular-network-are-slowly-closing/106432/

inaccessible or were not permitted to enter for safety reasons. Cells on wheels were used during this disaster; however, their deployment was problematic in flooded areas. The lack of connectivity caused complications with emergency coordination. Potentially, the most affected states of North Rhine-Westphalia and Rhineland-Palatinate could be covered with mobile service by 5 HAPS, functioning within hours and cruising for days with a radius of 70 km.

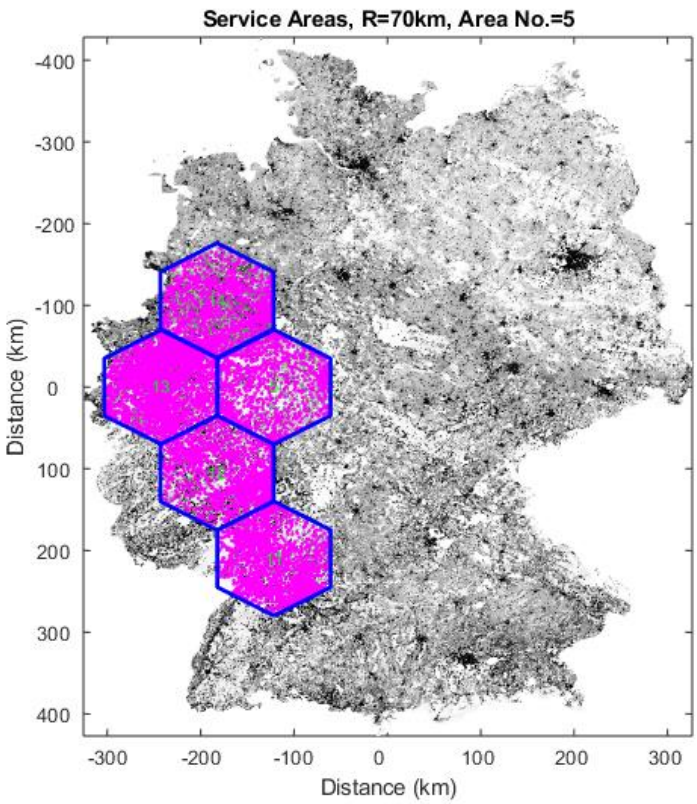


Figure 11: Map with depicted areas of potential HAPS deployment in the most affected regions of Germany during the flooding in 2021.

Natural disasters are usually limited to a specific region. Nevertheless, for recovery relief of the whole Germany, 31 HAPS would be necessary. They could be ideally backed up with satellite links to overcome terrestrial backhaul, which might be damaged.

Technical KPIs

Below are listed the key KPIs that were considered during the analysis. The modelling was performed for providing direct connectivity to UEs and assuming 8 years of operation.

Table 11: Technical KPI for Disaster Response in Germany

Information	Content unit	Input
Portable BS per single HAPS	Number	50
Users per portable BS	Number	1000

Radius for single HAPS coverage area	Km	70
Throughput per portable BS	Gbps	1
Total throughput per single HAPS	Gbps	10

Even though the economics behind this use case is not as crucial for deployment as for other use cases, economic analysis of HAPS solution indicates significant cost reduction, especially for the network sharing model. The network sharing scenario assumes a stratospheric platform to be shared by multiple operators.

The total cost of the HAPS disaster recovery solution would need to be lower than 200M € to be economically viable compared to cells on wheels, assuming 8 years of operation. For disaster recovery use case, the availability of governmental subsidies should also be considered.

Conclusions

By using HAPS, it is possible to restore communication in disaster area quickly, safely and extensively. In this use case, it may be required to provide communication with a total throughput of 10 Gbps or more per single HAPS. Profitability is not necessarily required in disaster relief scenarios. The adoption of HAPS for disaster recovery can be synergic with other use cases such as coverage of special events and tourist hotspots.

Private Networks

One of the characteristics of this use case is the need to provide either permanent or temporary services according to requirements from the customer. The service is required in specific dedicated areas, like a construction site, a mine, or an event. The analysis differs from the greenfield or whitespots use case, since the type of services and user/devices distribution is concentrated in the area of interest.

Methodology description

There are two possible ways to connect to users in temporary industrial network: (i) Cellular backhaul (CBH) where HAPS supports a backhaul between the core and the base station as an independent tunnel line and (ii) direct access (DA) where HAPS connects directly to the UEs. Connections via an inter-HAPS link or a HAPS-to-satellite link are also conceivable.

When a CBH system is used, the communication path is not directly to the UE but via “Ground station → HAPS → Portable BS → UEs".

When a DA system is used, the UE will connect directly with the HAPS, i.e. via “Ground station → HAPS → UEs”.

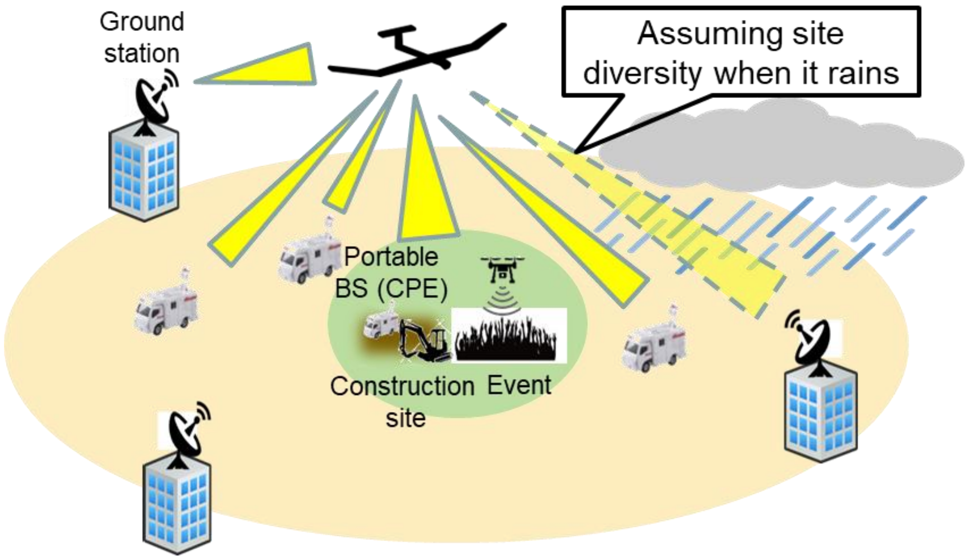


Figure 12: Cellular backhaul and direct access modes.

Use case analysis

Seasonal events, large-scale construction, or infrastructure development projects often require the rapid provision of communication systems for reach-back connectivity with the internet of enterprise networks. The duration for this temporal demand can vary between weeks, months, or years.

HAPS can be used to establish a temporary industrial network. Specifically, the way of establishing connectivity could be to fly in a point-multipoint datalink that connects deployable user terminals to a gateway feeder link.

Technical KPIs

The table below shows the KPIs used for the analysis of HAPS as a CBH system.

Table 12: Technical KPIs for the Private Networks use cases based on the CBH communication mode.

Information	Content unit	input
Portable BS per single HAPS	Number	15
Users per portable BS	Number	100
Maximum distance from the ground station	Km	50
Throughput per portable BS	Gbps	1
Total throughput per single HAPS	Gbps	15

Next, an example of annual revenue is shown here. Note that the revenue shown here is just an example of an initial review of business modeling.

$ proposed per user	2000
$ revenue per single HAPS	3M (=$2000×100 users×15 BS)

Considering depreciation is less than $3M on a yearly basis. Naturally, CAPEX and OPEX differ due to various factors such as HAPS aircraft and architecture.

Conclusions

By using HAPS, it is possible to provide communication systems for reach-back connectivity with the internet of enterprise networks rapidly. In this use case, it may be required to provide communication with a total throughput of 15 Gbps or more per single HAPS. In the considered example, profitability may be secured by limiting annual cost to around a couple of millions dollars.

Coverage over the sea

Offshore users lose connectivity as soon as they move more than a few tens of kilometres from land or out of the line of sight of the base station. While large ships are equipped with SatCom terminals, a vast amount of small and medium size boats and vessels remain unconnected. Establishing connections for offshore users will improve not only the control of the vessels but also communication convenience for users.

Methodology description

Similarly, to the private network use cases, there are two possible ways to connect to offshore users: (i) Cellular backhaul (CBH) and (ii) direct access (DA).

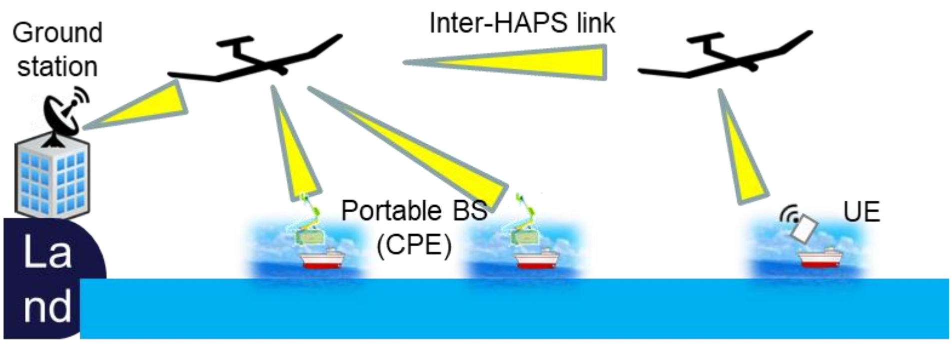


Figure 13: Schematic for the Coverage over the sea use case.

Use case analysis

HAPS can be used to establish an offshore user connection. Specifically, offshore users can directly access the LTE (or 5G) service link via HAPS from the onshore feeder gateway. Alternatively, it is possible to set up a CPE station on-board and use HAPS as a cellular backhaul (CBH). Furthermore, connections can be forwarded to the terrestrial gateway via an inter-HAPS link or a HAPS-to-satellite link, as shown in the figure above. The analysis of the use case is based on the example of Japan.

At the introduction stage of the service, attention should be paid to the operation in territorial waters that is easy to realize. Provision of the service in distances over 200 nautical miles or in international waters might not be considered for initial deployments. With the development of communication technology such as Inter-Satellite Link, it will be possible to expand the service area. As the service area expands, the feasibility of IoT use cases in addition to providing communication to mobile users may increase.

Technical KPIs

The table below provide an example of KPI when using HAPS as a CBH system.

Figure 14: Technical KPIs for the coverage over the Sea using the CBH mode of communication.

Information	Content unit	input
Portable BS per single HAPS	Number	10

Users per portable BS	Number	100
Maximum distance from the ground station	Km	50~200
Throughput per portable BS	Gbps	1
Total throughput per single HAPS	Gbps	10

Next, an example of annual revenue is shown here. Note that the revenue shown here is just an example of an initial review of business modeling. It is assumed that providing services to the sea will be more expensive than on the ground.

$ proposed per user	3000
$ revenue per orbit	3M (=$3000×100 users×10 BS)

Considering depreciation is less than $ 3M on a yearly basis. Naturally, CAPEX and OPEX differ due to various factors such as HAPS aircraft and architecture.

Conclusions

By using HAPS, it is possible to provide communication to offshore users rapidly. In this use case, it may be required to provide communication with a total throughput of 10 Gbps or more per single HAPS. In the considered example of Japan, profitability may be secured by limiting annual cost to around a couple of millions dollars.

Overall Conclusion

The analysis of the example use cases above has provided a good overview of the most important technical KPIs that a mobile operator will take in account when looking at the different HAPS solutions. The analysis has clearly highlighted that depending on the desired use case, e.g. the geography, the existing footprint of the mobile operator and the local economic conditions do enormously influence the outcome. Further deep dives in collaboration with HAPS suppliers will be needed in the future to draw more tangible conclusions. It is also acknowledged that the HAPS suppliers will have room for cost improvements, e.g. due to the maturing and scaling of the technology. It would be beneficial that the HAPS community considers the results of the analysis as a starting point to provide adaptive and cost-efficient solutions to the cited cases. One important point that has emerged from the analysis is that the HAPS solution should consider taking in account a non-uniform distribution of the service over a geographical area whilst also minimising the interference with terrestrial services.

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 withstand temperatures ranges 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, so that 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. To date, most of the HAPS launches have taken 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 and 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 dirigibles). These two classes can be 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. Stratospheric Platform, 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. Fixed wing platforms 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 (> 60 metres), and they require specific facilities to land/take-off and for maintenance.

Dirigibles (e.g Thales Stratobus, Sceye, Altran Ecosat) are the largest platforms, with higher capabilities in terms of payload weight (several hundred kg), power (> 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 dirigibles 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

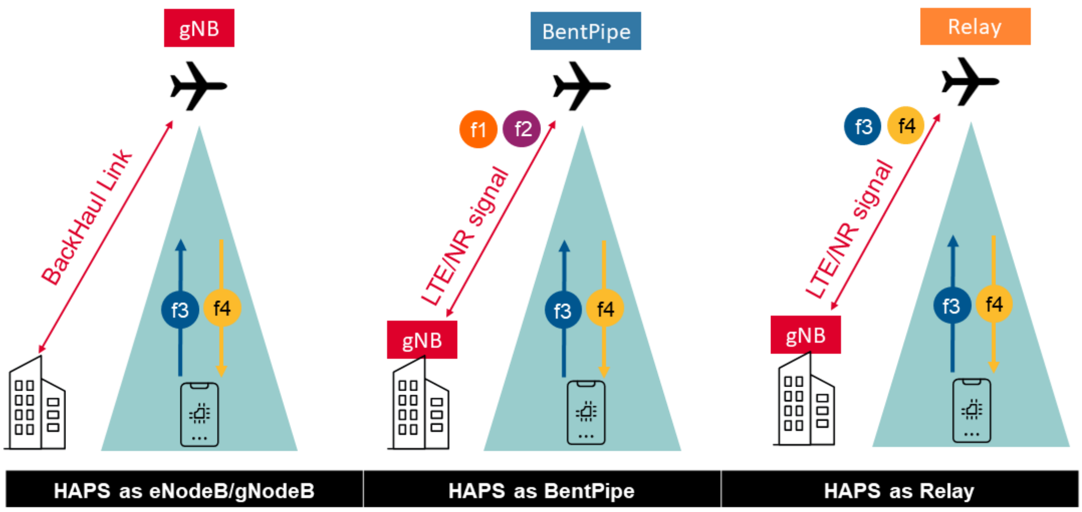
HAPS are equipped with specific technologies, such as propulsion, power management, battery storage, solar/fuel systems, safety, telemetry and flight/payload control and the on-board payload and specific subsystems. These systems are governed by the type of platform.

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. Alternately, 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 just 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

Spectrum for HAPS was initially discussed at the World Radiocommunication Conference 1997 (WRC-97). 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[23] **21.4-22 GHz**[24] **24.25-27.25 GHz**[25] **27.9-28.2 GHz**[26] 31-31.3 GHz[27] 38-39.5 GHz[28] 47.2-47.5 GHz, 47.9-48.2 GHz[29]	1885-1980 MHz, 2010-2025 MHz, 2110-2170 MHz[30] 1885-1980 MHz, 2110-2160 MHz[31]

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).

[23] In Australia, Burkina Faso, Cote d'Ivoire, Mali and Nigeria, as per 5.457.
[24] In Region 2 (Americas, Greenland and Pacific Islands), as per 5.530E.
[25] In Region 2, as per 5.532AA and 5.534A.
[26] 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.
[27] Globally, as per 5.543B.
[28] Globally, as per 5.550D.
[29] Globally, as per 5.552A.
[30] In Regions 1 (Europe, Middle East, CIS, Mongolia and Africa) and 3 (APAC and Iran), as per 5.388A.
[31] 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 a 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.

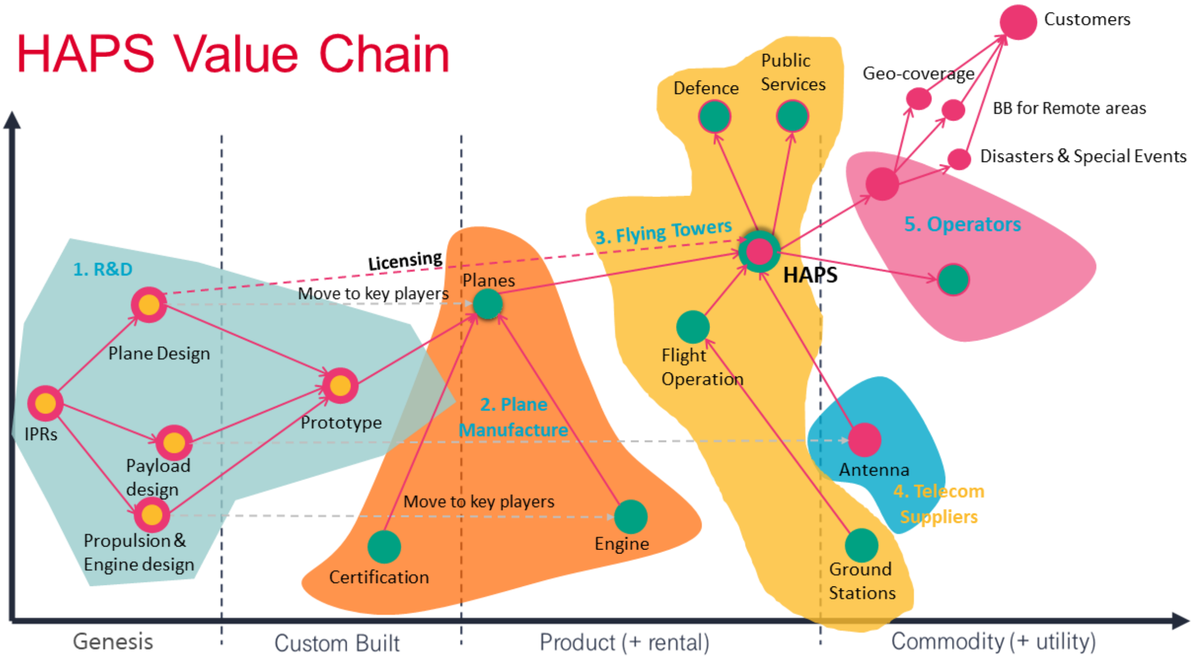
5. **Mobile network operators** will play an important role, as they deliver telecoms services to customers and will be one of the main cash flow sources in the chain.

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”.

This second version of the whitepaper has tried to provide an economic analysis of some of the most relevant use cases described in this document. The approach taken on the cost analysis, the mobile operators have come up with the costs of terrestrial network roll-out for chosen use cases, which represents a benchmark for the vendors to consider when constructing the platforms. Mobile operators have a good overview of the cost to provide terrestrial services but they lack knowledge of the costs involved in HAPS platforms.

While acknowledging the progress of HAPS technology, closer collaboration between the HAPS providers and the Mobile Network Operators is needed to look at both technical and economic performances and further define the most suitable applications for HAPS. Industry organisations like the HAPS Alliance should also advance collectively to unlock: the use case, the business case, the KPIs, spectrum, regulations, flight approval and aircraft certification and any generic economic considerations.

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.
- Review of given input for Mobile Operator's use cases and prove economical as well as technical feasibility and environmental sustainability in deeper analysis.
- 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.
- Recognise the need of a future proof spectrum management to cater for HAPS solutions considering the existing terrestrial services and the different conditions an needs of each country.

Investors:

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

Appendix

Stratospheric Platforms Information Sheet

This section offers a high level information of some of the current available solutions for Stratospheric Platforms. The information sheet provides a structured approach in order to provide similar type of information for each platform, to easily assess the different solution and to understand for which use case could be more suited.

HAPS Mobile		
Company name and link	HAPSMobile Inc. https://www.hapsmobile.com/en/	
Company around since (year)	Established: December 21, 2017 Founder companies: SoftBank Corp. and AeroVironment, Inc	
First test flight	[First Stratospheric Test Flight] Date: September 21, 2020 Maximum altitude: 62,500 feet (approx. 19 kilometers) Total flight time: 20 hours and 16 minutes Airport: Spaceport America, New Mexico, USA https://www.hapsmobile.com/en/news/press/2020/20201008_01/	
Commercial status	In development. (It is expected to be commercially available around 2027)	
Business Model	The main business model for HAPSMobile will be the leasing and sales of HAPS aircraft, and also the maintenance and operation of the system. https://www.hapsmobile.com/en/service/	
Cruising altitude, speed, time to ascend and descend	(As of 2021) Name:Sunglider Cruising altitude: Around 20km Cruise Speed:110 km/h https://www.hapsmobile.com/en/technology/	
Aircraft weight and dimensions (wing span)	(As of 2021) Name:Sunglider Wingspan: 78 meters https://www.hapsmobile.com/en/technology/	
Payload weight, dimension and specification	Non-disclosure	
Power consumption for the aircraft and payload	Non-disclosure	
Energy source	(As of 2021) Name:Sunglider Energy source: Combination of solar power and high energy density lithium ion battery https://www.hapsmobile.com/en/technology/	
Endurance time	(As of 2021) Name:Sunglider Flight Duration: Several months https://www.hapsmobile.com/en/technology/	
Optimal area of coverage	Non-disclosure	
Primary application	Communication (current smartphones, etc), disaster relieve, IoT, Drones https://www.hapsmobile.com/en/service/	

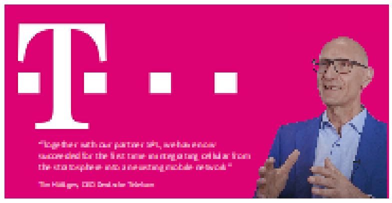
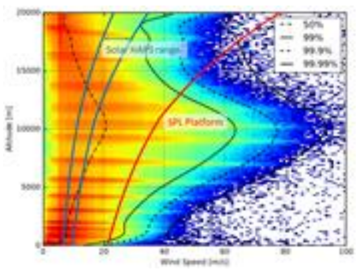
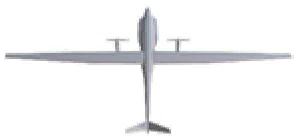
SCEYE		
Company name and link	Sceye Inc. 50 George Applebay Way Building 200 Moriarty, NM 87035 USA https://www.sceye.com/	
Company around since (year)	Sceye was founded by Mikkel Vestergaard Frandsen in 2014. Mikkel is also owner of Vestergaard and LifeStraw, both global social enterprises dedicated to using material science in public health, food security and safe-drinking water. Sceye leverages from Vestergaard's 25+ year expertise in material science to tackle a new humanitarian challenge: to extend broadband coverage to every corner, so that nobody's left behind	
First test flight	In 2016, Sceye launched its first test flight. A 9 ft scaled-down prototype was flown at 65,000 ft altitude with the purpose of validating fabric, seaming method, hull pressure, thermal systems, and solar panels	
Commercial status	The Sceye HAPS solution is currently in its pre-commercial demonstrator phase. This demonstrator program includes sponsors (customers paying for demonstration flights), collaborating on the delivery of key payloads and defining the flight mission. In the case of Telecom demonstrator flights, the main objective is to characterize field capabilities and performance: 4G LTE propagation and range characterization, link budget analysis, performance of a state-of-the-art MIMO active antenna array, which will provide key data for evaluating and determining the use cases and economics of this class of NTN solution. Sceye have flown 2 sponsored Telco missions in 2021 and have 2 additional flights already scheduled for 2022, with more sponsors in the pipeline. Sceye expects to be commercially available in the US in 2023 and shortly after in EMEA.	
Business Model	Sceye primary business model for Telcos is to provide a "Platform as a Service", meaning no large upfront CapEx investment, just annual OpEx.	
Cruising altitude, speed, time to ascend and descend	Sceye HAPS will operate from the stratosphere at 62,000 - 65,000 feet (18 - 20 km). Filled with helium for buoyancy, Sceye HAPS does not need to stay in motion to remain aloft. Therefore,	

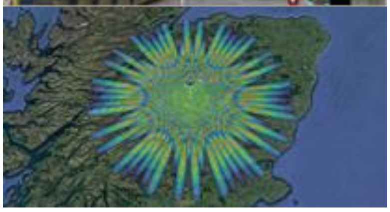
	they can keep station over a specific location for a long time.	
Aircraft weight and dimensions (wingspan)	Not applicable for LTA	
Payload weight, dimension and specification	Sceye HAPS solution will act as a Base Station in the sky, with a projected coverage area of up to 150km radius. Sceye is developing a payload based on OpenRAN technology that supports 2G/3G/4G/5G NR Radio Access Networks (RAN) as well as an active array antenna with 3D beamforming technology with 100-200 independently activated beams. SWaP is TBD During our demonstrator phase we are using same spectrum as our mobile operating partners. We are hoping the next World Radiocommunication Conference (WRC) in 2023 will dedicate spectrum to HAPS.	
Power consumption for the aircraft and payload	The total energy calculation is driven by the mission, condition, and payload SWaP - i.e., the CONOPS.	
Energy source	Sceye HAPS are solar powered during the day and battery powered at night. Both the solar capture and battery technology have been patented by Sceye. To date, Sceye has 5 patent families. The Sceye R&D team is constantly striving to improve our airship technology to maximize the performance of each product. We expect considerable advances in both solar panel and battery efficiency over the next couple of years.	
Endurance time	Sceye HAPS have neutral buoyancy and require minimum power to maintain altitude and keep station. Since they are solar powered, they can be operated on a 24x7 basis for long periods of time (months if not years). Our expertise in material science have resulted in extended material lifespan but we plan to take the HAPS down for annual service.	
Optimal area of coverage	With current technology, operational range today is approximately ±40º from Equator. Yet, 80% of the unserved/underserved population fall within current operational range	
Primary application	We are engaging with customers on a wide range of applications including: • Telecommunications • GHG emissions monitoring (and urban air quality - we're part of the HAPSView program with ESA) • Natural resource surveying, mapping, monitoring	

	• Wildfire monitoring and early detection • Science missions - earth, ocean, and atmospheric sciences • Maritime safety and surveillance (we’re part of the ARTES program within ESA)	

Stratobus™		
Company name and link	Thales Alenia Space	
Company around since (year)	Thales Alenia Space has been designing and supplying innovative satellite solutions for more than forty years. A joint company between Thales (67%) and Leonardo (33%), Thales Alenia Space also forms the Space Alliance with Telespazio to offer a complete range of solutions including services.	
First test flight	Stratobus™ is in development with a first test flight of a reduce scale demonstrator expected from 2024.	
Commercial status	Stratobus™ is in development, it should be commercially available from 2030 and produced in several European sites (France, Spain …).	
Business Model	Stratobus™ is initially designed for Defence & Institutional markets, but a commercial version, specifically optimized for telecommunication needs, is also programmed. HAPS are not yet at the level of maturity for full service. Consequently the Business Model envisaged today by Thales Alenia Space is still open, but a first approach is to be positioned as Manufacturer and/or MRO.	
Cruising altitude, speed, time to ascend and descend	Stratobus™ is an Unmanned airship with a flight altitude range from 18 – 20 km. It can keep the station to operate or move to change position. The maximum flight air speed is 20 m/s over 24 hours. Main operational features are ascent time <4h and descent time >8h, it can operate >1000 km from its launch base. The mission duration is about a year. The certification process was started in 2017 with EASA.	
Aircraft weight and dimensions (wing span)	Stratobus™ is an Airship of 140 m long and 32 m diameter, for a total mass of about 10 tons.	
Payload weight, dimension and specification	A high throughput payload of 250kg/5 kW and few m3 can be hosted on Stratobus™ and large antennas can be fitted Telecom commercial applications are 4G/5G mobile broadband access, residential access and backhauling. In each case the feeder link uses HAPS bands (Ka/Q/V). IMT bands are usable for 4G/5G access, and HAPS bands (Ka/Q/V) for residential access and backhauling.	

	Telecom applications also include connectivity to Drones, UAVs or autonomous cars. Telecom applications can also include optical point-to-point connectivity, either between several Stratobus^{TM} (at maximum distance of about 500 km), or between Satellite and Stratobus^{TM}, or between ground and Stratobus^{TM}.	
Power consumption for the aircraft and payload	The payload power consumption is of 5000W.	
Energy source	Stratobus^{TM} is fully autonomous in energy, solar powered in combination with battery storage, allowing night and day operation, 24/7, for long-term missions.	
Endurance time	Up to 1 year in operation intra-tropics.	
Optimal area of coverage	Stratobus^{TM} can fly worldwide location, with a yearly permanence intra-tropics, and seasonal flights extra-tropics excluding the poles.	
Primary application	Stratobus^{TM} is a multi-mission solution with primary target applications that are Intelligence, Surveillance and Recognition, Disaster Relief, Military and 5G/6G telecommunication, GNSS complement.	

Stratomast		
Company name and link	Stratospheric Platforms Limited (SPL) www.stratosphericplatforms.com The HAP is called 'Stratomast'.	
Company around since (year)	Company founded in 2014, significant investment by Deutsche Telecom in 2016	
First test flight	August 2020 - Hydrogen fuel cell - laboratory tested up to 45kft altitude October 2020 - first payload flight test in Germany, altitude 45kft, flight time 3 hours, 4G connectivity demonstrated, prove that spectrum was used more efficiently in rural areas. First flight in 2023 with full stratospheric aircraft flight test planned 2024	[Mobile radio from the stratosphere - YouTube] 
Commercial status	The Stratomast aircraft is in development. Commercial service commencing 2025	
Cruising altitude, speed, time to ascend and descend	Cruise altitude = 60kft Aircraft Speed = 150 knots Time to ascend = 3hrs Time to descend = 1 to 4 hrs Certified for flight in Controlled Airspace. Able to station hold in the stratosphere due to high power thrust and persistent cruise capability.	
Aircraft weight and dimensions (wing span)	Take off Weight = 4000kg Wing span = 56m	
Payload weight, dimension and specification	Weight = 140kg Power = 20kW continuous power 24/7 Size = 3x3m	

	Total downlink array data rate >60 Gbps data transmission rate. Type = Up to 500 Phased Array steerable beams, all independently steered and activated/deactivated Latency = < 1 ms. Fronthaul Frequency = 2.1 & 2.6GHz 100% geographic coverage Radius = >70 km (15,000 km^2 area) The solution acts as a relay/bent pipe, the number of terrestrial stations connected depends on the use-case	
Power for aircraft & payload	Peak continuous total power consumption 130kW	
Energy source	Liquid Hydrogen (exhaust is water vapour)	
Endurance time	6 to 9 days	
Optimal area of coverage	No limitations, can cover the full surface of the earth day & night.	
Primary application	Neutral host mast in the sky acting simultaneously as a mobile and fixed wireless system communicating directly to a wide array of low power user devices, for example mobile phones, MiFi and IoT systems. Fully compatible and integrated with existing Telco infrastructure. 3G, 4G, 5G and beyond compatible. OpenRAN standards.	

Zephyr		
Company name and link	Airbus Defense and Space https://www.airbus.com/en/products-services/defence/uas/uas-solutions/zephyr Zephyr Solar Powered HAPS https://www.airbus.com/en/products-services/defence/uas/uas-solutions/zephyr	
Company around since (year)	1970	
First test flight and Stratospheric Flight Experience	**Zephyr Prototype** - 2010 Set endurance record of 14 days, 22 minutes for UAVs. **Zephyr 8 Model** – 11 July 2018 Publicly released - "Taking off from Arizona, US on 11 July, Airbus Defence's solar powered UAV, the British-built Zephyr S, has broken the existing endurance record for unrefuelled, unmanned flight by staying aloft for 25 days, 23 hours and 57 minutes. This, the maiden flight of the production Zephyr S HAPS (high altitude pseudo satellite) for the UK MoD, once verified, almost doubles the existing endurance flight record." **Key Stratospheric Flight achievements to date** 1. Longest duration in Stratosphere for fixed wing UAV Solar HAPS 25 days, 23 hours, 57 mins 2. First HAPS to exit into National Air Space with approvals 3. Highest altitude of 76100ft 4. Ability to transit 1000nm per day 5. 2435hrs of Stratospheric flight to date	https://youtu.be/0IZW7llqReM
Commercial status	Pre-Commercial and industrialisation phase	
Business Model	Depends on application. Platform as a Service & Connectivity as a Service models and Use Cases will dictate the specific Business Model.	

Cruising altitude, speed, time to ascend and descend	FL600-FL800 10hrs Ground to Stratosphere	
Aircraft weight and dimensions (wing span)	**Zephyr 8 (current generation)** 75kg 25m **Next Generation*** 100kg+ 35m+	**Zephyr 8 (current generation)** 
Payload weight, dimension and specification	**Zephyr 8 (current generation)** 6-10kg 1-14 beams Fixed or steerable beams BS or Relay Frequency – location specific Backhaul Frequency – location specific** Single terrestrial ground station Radius coverage 25-75km **Next Generation*** 15-20kg 1-14 beams Fixed or steerable beams BS or Relay Frequency – location specific Backhaul Frequency – location specific Single terrestrial ground station Radius coverage 25-100km	
Power consumption for the aircraft and payload	Zephyr 8 – 350Wh/kg Next Generation* – 850Wh/kg	
Energy source	Solar array with Lithium ion batteries	
Endurance time	Current generation record of 26 days with planned development roadmap towards 3-6 months depending on location/mission Next generation planned development roadmap toward 6-12 months depending on location/mission	

Optimal area of coverage	+/- 30 Latitude all year (planned) +/- 50 Latitude short duration (planned)	
Primary application	Connectivity • Direct to Device Other Secondary Connectivity applications: • Backhaul • Rural • Disaster Recovery • Maritime • Relay • IoT • Automated Vehicles/Drones/Machinery Earth Observation applications: • Imagery • Tracking • Video • IR • Agriculture • Security • Environmental	

*All Next Generation items are subject to future development – currently gathering specific Use Case requirements

**Backhaul and Service Frequencies – use of HAPS allocated by WRC19 & 23 where applicable, local MNO Spectrum Use for Direct to Device Services presumed.

GSMA

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