HAPS Alliance
HIGH ALTITUDE PLATFORM STATION

HAPS Reference Architecture Series

HAPS Advantages in an Era of Satellite Connectivity

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Introduction: HAPS Advantages in an Era of Satellite Connectivity

This paper will explore the exciting use cases and architecture of high altitude platform stations (HAPS). Our purpose is to help governments, investors, and potential customers understand the scenarios in which HAPS could offer better connectivity than satellites, complementing cellular terrestrial networks with direct-to-handset applications.

HAPS are typically balloons or solar/hydrogen-powered airplanes, which can act as base stations, staying aloft in the stratosphere (at a typical altitude of 18-24 km) for several weeks or months. Like satellites, HAPS can provide non-terrestrial network (NTN) services. HAPS advantages over satellites include:

1. Unlike satellites, HAPS can work with most end-users' handsets.
2. HAPS can cover a large service area with a higher throughput and lower latency than satellite links.

They are ideal for bringing high-speed broadband to remote and unserved areas, supplementing existing networks.

In this document, you'll find analyses of many potential use cases for HAPS, including:

1. Providing coverage in areas with no cellular networks.
2. Filling in gaps in cellular coverage.
3. Emergency communications/disaster recovery.
4. Extending coverage over the sea.

We also consider aspects of the network topology and how HAPS can be coordinated with low Earth orbit (LEO) and geosynchronous Earth orbit (GEO) satellites., before exploring different backhaul options and the necessary link budget in a scenario where the coverage area is stricken by bad weather. The paper also considers the integration of HAPS with cellular infrastructure, the advantages the technology offers over traditional satellite-based communications and outlines the technical characteristics of HAPS.

Executive Summary

HAPS offer an economical way to support a range of use cases, including greenfield connectivity in areas where there are no terrestrial networks and filling in gaps in cellular coverage. (These gaps are known as “white spots” and offer additional challenges by being typically small and geographically non-contiguous areas.) HAPS can typically provide connectivity of between 50 and 100 Mbps per beam, with a peak of 200 Mbps. As a result, each beam can support ~2,000 concurrent voice calls.

HAPS can support automotive-related, public safety and agricultural use cases, as well as other commercial services. Automotive use cases include emergency calls, the remote unlocking of shared cars, the provision of safety-related traffic information, such as road hazard warnings, vehicle software updates and in-car entertainment. HAPS can also connect various environmental sensors to provide early warnings of natural disasters, while agricultural use cases include crops and soil health monitoring, geo-fencing (to detect movement into and out of the farm) and livestock tracking.

In the aftermath of a disaster, HAPS can help affected communities overcome terrestrial communication blackouts. By enabling swift and efficient communication, HAPS can enhance situational awareness, support search and rescue efforts and aid in the recovery and rebuilding process.

HAPS can also extend coverage out to sea, supporting tourism and recreation, offshore energy, mineral extraction, shipping and other parts of the marine economy.

The following table outlines the performance requirements for each of the use cases considered in this paper.

Use Case	Required Coverage	Required Throughput	Required Latency
Greenfield coverage	Broad coverage	1 ~100Mbps	<10 msec (radio link)
White spot reduction	Broad coverage	100Mbps ~ 1Gbps (especially for downlink)	<10 msec (radio link)
Emergency communications / disaster recovery	Broad coverage	10Mbps ~ 1Gbps (especially for downlink)	Not critical
Extended coverage over the sea	Narrow/broad coverage	50Mbps - 1Gbps	<10 msec (radio link) or even longer

In most scenarios, HAPS will work with other networks. Indeed, the coordinated communication of HAPS and satellite platforms can provide a resilient network backbone for several use cases. These multi-layered non-terrestrial networks (ML-NTNs) can support earth observation, beyond-line-of-sight command and control use cases, as well as the extension of cellular connectivity to greenfield areas and white spots. In particular, HAPS can play a critical role in providing a ML-NTN backhaul backbone in coordination with LEO/GEO satellites. Furthermore, HAPS can be a key element of an integrated terrestrial and non-terrestrial access network architecture, encompassing space, aerial/stratospheric and terrestrial infrastructure.

While there are moves to provide satellite-based communications directly to smartphone devices, the achievable data rates are rather modest due to the link budget constraints. HAPS, by comparison, are much closer to the user device (ranging from ~15 km to a few tens of km) allowing for much higher throughput services.

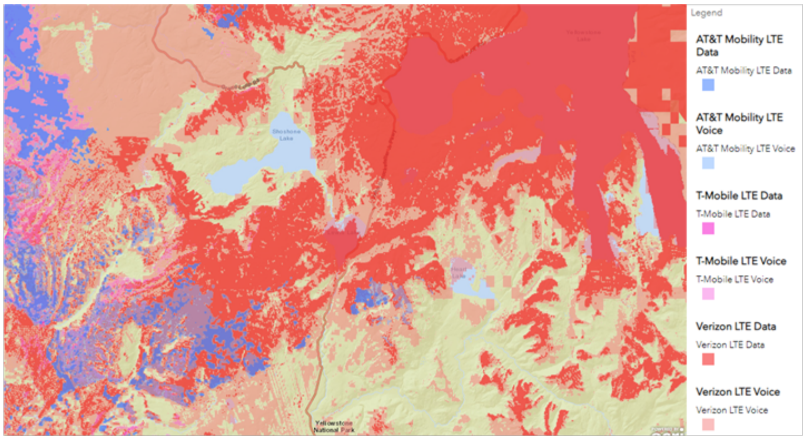
Analysis of HAPS Use Cases

This section outlines various use cases for HAPS, explaining the value the technology can create and the performance requirements for each use case.

HAPS can provide connectivity in areas where there are no terrestrial cellular networks, otherwise known as greenfield coverage. This is important for bridging the digital divide and ensuring that all communities have access to essential communication services.

Scenario One: Automotive

In greenfield areas, HAPS can support a number of automotive-related use cases, including emergency calls, remote unlocking of shared cars, the provision of safety-related traffic information, such as road hazard warnings, vehicle software updates and in-car entertainment. For example, this map shows the gaps in 4G coverage in Yellowstone National Park, as of May 15, 2021, which could be filled by HAPS providing connectivity across the park. first contemplated by the ITU, HAPS was envisioned as an alternative physical topology which could be used to augment traditional terrestrial network deployments.



Source: US FCC: https://fcc.maps.arcgis.com/apps/webappviewer/index.html?id=6c1b2e73d9d749cdb7bc88a0d1bdd25b

Key Requirements:	
Coverage:	Broad
Throughput:	< 1Mbps (Safety), ~100Mbps (Autonomous driving)
Latency:	< 10ms

Scenario Two: Public Safety

In regions where it isn't commercially feasible to deploy either terrestrial or satellite solutions, HAPS can provide public safety services. HAPS can be positioned over those areas to detect natural disasters (e.g., floods, fires) by connecting to appropriate sensors. Should a natural disaster occur, HAPS can be vital for enabling communications during disaster relief and recovery efforts — we explore those scenarios in more detail below.

Key Requirements:	
Coverage:	Broad
Throughput:	~100Mbps
Latency:	< 10ms

Scenario Three: Agriculture and Farming

Given that many farms are in remote and unconnected areas, monitoring agriculture entails significant overhead in terms of staff hours and/or use of expensive and unreliable satellite options. HAPS can provide the 180 kHz (as defined by 3GPP) required to connect 4G NB-IoT sensors in remote farms. Agricultural use cases for HAPS include crop and soil health monitoring, geofencing (to detect movement into and out of the farm) and livestock tracking.

Key Requirements:	
Coverage:	Broad
Throughput:	< 1Mbps
Latency:	Not Critical

White Spot Reduction — Filling in Gaps in Cellular Coverage

White spot reduction aims to reduce or eliminate areas with limited or no network coverage. HAPS can remove the need to deploy expensive infrastructure, such as cell towers, to cover these areas, which are often small and non-contiguous.

Scenario One: Highways/Roads (Uninhabited Area with Needs for Communication)

In Japan, the government has put forward its *Vision for a Digital Garden City Nation* to revitalize rural areas. The vision calls for the deployment of digital infrastructure, such as optical fiber, 5G, data centers and submarine cables. The government's related *Infrastructure Development Plan for a Digital Garden City Nation* includes specific measures for NTNs, such as HAPS and satellite communications, seamlessly connecting land, sea, air and space, expanding communication coverage and promoting the implementation of advanced solutions.

The plan requires uninhabited areas to be covered with 4G/5G as soon as possible to improve convenience, safety and security for people traveling on expressways and national highways. The government wants 99% of these roads to be covered by 5G by the end of 2030. That goal requires a significant number of base stations to be installed.

For roads in mountainous areas where electric power and optical fiber may not be available, coverage by NTNs is set to be an important factor. Some use cases, such as the remote control of unmanned vehicles, reliable connections between vehicles and infrastructure, and the provision of detailed 3D maps, have demanding requirements (see table).

Key Requirements:	
Coverage:	Broad
Throughput:	> 100Mbps
Latency:	< 10ms (radio link)

Scenario Two: Rural Area (Can't Be Fully Covered by Terrestrial Networks Profitably)

As mentioned, the Japanese government is aiming for 99% of the population to be covered by 5G by 2030. The conventional provision of communications to rural areas is expensive due to the high cost of deploying ground base stations and the associated backhaul links. For example, to cover Hokkaido prefecture (a specific 100 km radius area), approximately 1,600 ground base stations are required, at a 10-year-estimated total cost of ownership of $445 million. Divided by the number of eligible customers in the region, the cost per customer would be about $150 per month, which is higher than the current monthly average revenue per user (ARPU) of $40-70 in Japan. Therefore, it isn’t economically feasible to reduce the number of white spots by using only ground base stations.

By contrast, a single HAPS can cover many white spots in non-contiguous situations. In that sense, HAPS can be a suitable solution. The following table shows the requirements for white spot coverage.

Key requirements:

Coverage: Broad
Throughput: ~1Gbps (especially for Downlink)
Latency: <10 msec (radio link)

Emergency Communications and Disaster Recovery: Backing up Damaged Terrestrial Networks

Climate change is creating more frequent extreme weather events. While deforestation on mountain slopes and hills is increasing the number of landslides and mudslides, urbanization is reducing the areas of exposed soil that can absorb water, raising the risks of floods.

In the aftermath of a disaster, affected communities often face communication blackouts, hampering their ability to seek assistance, contact loved ones, or access vital information. There is also a need for reliable and timely information exchange among emergency responders, affected communities, and relevant authorities to enhance situational awareness, support search and rescue efforts, and aid in the recovery and rebuilding process.

Full coverage and throughput of up to several tens of Mbps are required to enable safety confirmation, disaster and emergency information on the surrounding area.

Scenario One: Flash Flooding in Germany

In July 2021, storms and heavy rains affected vast areas of Germany, causing loss of life, damaged infrastructure, and the overwhelming of emergency services providers. Terrestrial mobile network sites were damaged, resulting in the loss of communication for several days. Conventional disaster recovery measures, such as cell-on-wheels solutions, were not available due to the scale of events, or not able to reach the areas due to damage to road infrastructure.

Source: https://www.thenationalnews.com/world/2023/08/03/germanys-valley-of-floods-is-braced-to-withstand-future-disasters/

One of the affected areas was the Bad Neuenahr-Ahrweiler region (Stickings, T. (2023, August 2). *The Ahr with Burst Banks 2 Years Ago.* The National.), where about 100,000 inhabitants were impacted in an area of about 400 square kilometers. The region is normally served by approximately 50 cell sites (110 sectors), which were mostly out of service for several days. The deployment of temporary coverage solutions was complicated by damaged bridges and ground infrastructure. However, such an area could be effectively covered by a single HAPS station, supported by a feeder link provided by a network of ground stations, co-deployed with surrounding terrestrial base station sites.

Scenario Two: Disasters and Natural Emergencies in Africa

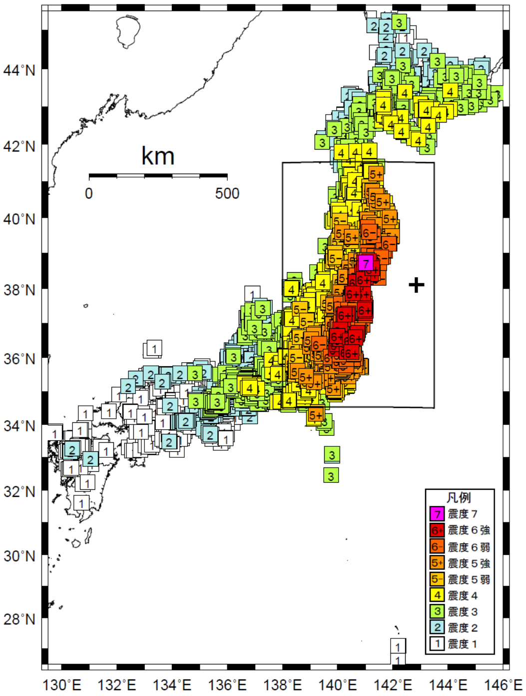
In Africa, natural disasters frequently impact infrastructure, especially roads and telecommunication networks. For instance, heavy rains, floods and landslides damaged about 1,200 cellular towers in South Africa in 2022. Access to the affected sites by engineers was significantly hampered by damage to roads. In such cases, HAPS can serve as an emergency response infrastructure to restore connectivity and facilitate the work of first responders, saving lives.

The International Telecommunications Union (ITU) advocates that every country should develop a national emergency telecommunication plan (NETP) as a framework for disaster risk management. The aim is to avoid a lack of communication and coordination that could put many more lives at risk. HAPS provide disaster-resilient infrastructure that can mitigate the impact of other network outages during emergencies.

Scenario Three: Earthquake in Japan

On March 11, 2011, a magnitude 9.0 earthquake occurred off the Sanriku coast in Japan (AKA Great East Japan Earthquake of 2011). The Pacific coast from the Tohoku region to the Kanto region was severely damaged. The earthquake and resulting tsunami caused extensive damage to telecoms facilities, with many cellular base stations collapsed or washed away. In addition, telecoms service was suspended one day after the disaster due to the battery depletion caused by a widespread power outage. The earthquake concentrated communications, resulting in widespread network congestion for a relatively long period of time.

About 29,000 base stations were out of service. It took about two months for the telecoms companies to restore service in most areas (Ministry of Internal Affairs and Communications. (2011). *Information and Communications in Japan Year 2011*.)[1]



The Japanese government predicts that there is 70%-80% probability of a Nankai Trough earthquake (magnitude 8-9) within 30 years[2]. In the case of a major disaster, 40% of the cellular

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[1] WHITE PAPER Information and Communications in Japan Year 2011 (https://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h23/pdf/n0010000.pdf, in Japanese)

[2] Long-term evaluation on Active faults and trench earthquakes published on January 13, 2023 (https://www.jishin.go.jp/main/choukihyoka/ichiran.pdf, in Japanese)

base stations in the affected areas could go down (see table), and it would take several days until communications are restored[3] (Damage Assumption for a Nankai Trough Earthquake (Damage to Facilities, etc.). In such a case, the presence of coverage from the sky would be significant. As the time limit for saving lives in a disaster is estimated to be 72 hours, it is important to have sufficient quality of service (QoS) to enable video transmission so that the disaster situation could be quickly assessed.

	Outage Rate of Cell Phone Base Stations (%)				Estimated Number of Days for Restoration **(95% Restoration)**
	Immediately after the Disaster	1 Day after the Disaster	4 Days after the Disaster	1 Week after the Disaster	
① Tokai Region	7%	81%	7%	6%	Approx. 1 Week
② Kinki Region	7%	13%	5%	2%	Few Days
③ Sanyo Region	1%	1%	-	-	Few Days
④ Shikoku Region	12%	81%	18%	16%	Approx. 3 Weeks
⑤ Kyushu Region	5%	78%	5%	5%	Few Days
Total Amount	6%	40%	6%	5%	

Cabinet Office, Government of Japan. (n.d.). Damage assumption for a Nankai Trough earthquake (partially edited)

Scenario Four: Hurricane Harvey in the U.S.

Hurricane Harvey was a devastating Category 4 hurricane that made landfall on Texas and Louisiana in August 2017, causing catastrophic flooding and over 100 deaths. According to the FCC[4], Hurricane Harvey knocked out cable, internet or telephone service to more than 180,000 homes, 364 cellular towers and disrupted service at 16 centers that process 911 calls in Texas and Louisiana (*Hurricane Harvey, 2017)*. As shown in the diagram, the hurricane also took out more than 50% of the cell sites in various coastal counties.

The fixed networks were affected as well. On August 28th there were at least 189,487 fixed-line subscribers without service in the affected areas. This included users who got service from cable systems and wireline providers. There were 19 non-mobile switching centers out of service and 22 switching centers on back-up power.

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[3] Damage Assumption for a Nankai Trough Earthquake (Damage to Facilities, etc.) (https://www.bousai.go.jp/jishin/nankai/taisaku_wg/pdf/1_sanko.pdf, in Japanese)

[4] *Hurricane Harvey*. (2017). Federal Communications Commission. https://www.fcc.gov/harvey

Key Performance Requirements

The platform performance requirements for emergency response services largely depend on the scale of the event. For instance, the areas affected by the floods in Germany in 2021 could be covered by a single high-capacity HAPS, or five low-capacity HAPS stations.

Key Requirements:	
Coverage:	Area of disaster (broad)
Throughput:	~10Mbps (emergency services) to ~1Gbps (full services)
Latency:	Not Critical

In an emergency response use case, HAPS need to have sufficient quality of service (QoS) mechanisms to allow traffic prioritization to defined user groups, with preferential access over common users.

In areas where the relevant ground infrastructure is not available, a satellite backhaul solution could be used, allowing deployment effectively anywhere where the satellite services are available. However, this backhaul method may become a capacity bottleneck, further emphasizing the need for a robust traffic prioritization strategy.

Extended Coverage over the Sea: Providing Connectivity in Proximity to Shores

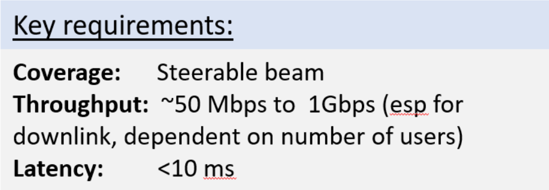
The marine economy is large and varied. But terrestrial LTE networks, comprised of land-based towers, often don't provide coverage much beyond coastlines. Non-terrestrial networks, such as HAPS, could be employed instead.

Some of the largest sectors of the marine economy include tourism and recreation, offshore energy and shipping. Each of these sectors has a need for network connectivity.

Scenario One: Tourism and Recreation

Providing network connectivity to ships and other watercraft associated with tourism and recreation can help fill a gap in traditional terrestrial networks. Larger tourist ships, such as cruise liners, are expected to carry 31.5 million people in 2023.

The average capacity of a single cruise ship is around 3,000 passengers, and these passengers are increasingly expecting network connectivity on board the ship. To effectively cover a cruise ship, a beam can be very targeted, with low latency and high throughput requirements to service many passengers at once. Transmissions at lower frequencies are better able to penetrate inside the ship.



Key requirements:

Coverage: Steerable beam
Throughput: ~50 Mbps to 1Gbps (esp for downlink, dependent on number of users)
Latency: <10 ms

Scenario Two: Offshore Energy and Mineral Extraction

The ocean and the ocean floor are rich in mineral content and natural sources of energy (wind and tidal). Around a third of the oil and gas extracted worldwide comes from offshore sources[5] (WindEurope. (2022, April 2). *European Offshore Wind Farms Map*.), while there were 292 operating projects for offshore wind energy in the U.S. as of May 2023[6] (Wind Energy Technologies Office, 2023; Wind Europe, 2022). In Europe, offshore wind farms are also growing fast[7] (*European Offshore Wind Farms Map Public*, 2024). HAPS can help meet the emerging needs for network infrastructure as these energy and mineral extraction requirements grow.

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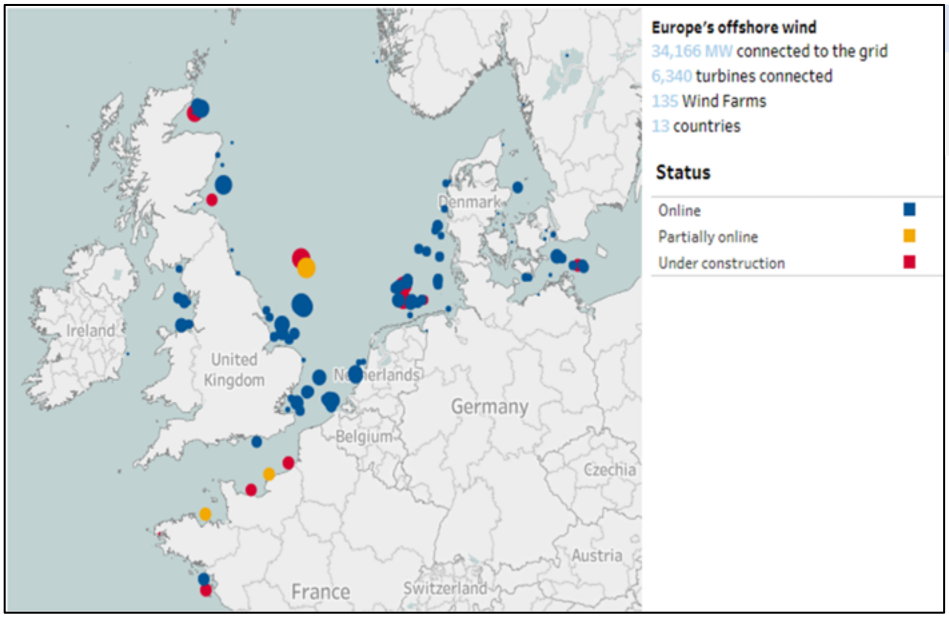
[5] https://www.boell.de/en/2017/05/20/energy-ocean-where-does-future-lie

[6] https://www.energy.gov/eere/wind/articles/offshore-wind-market-report-2023-edition

[7] https://windeurope.org/intelligence-platform/product/european-offshore-wind-farms-map-public/

Network connectivity to support energy production requires a wide area with relatively low throughput.

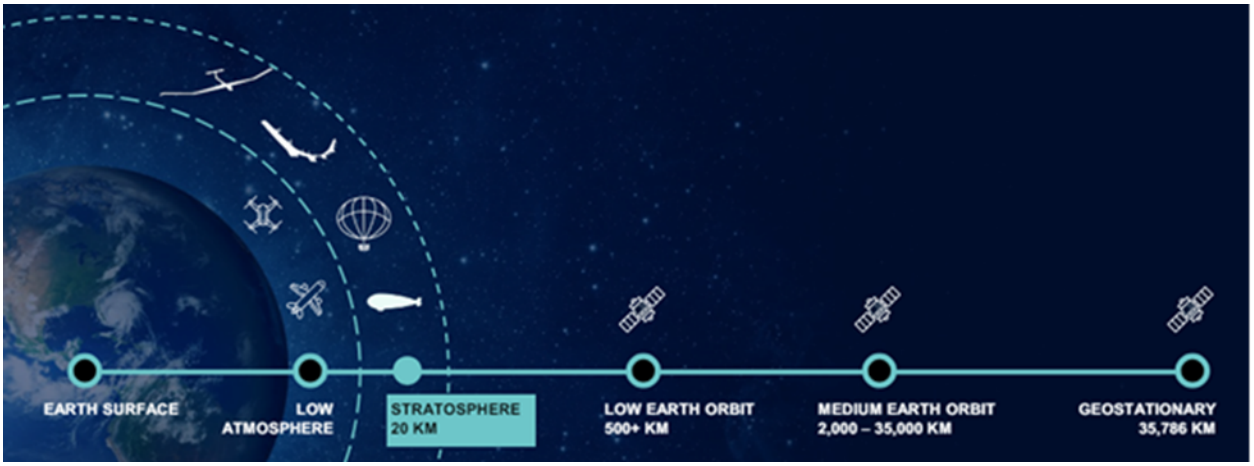


Key requirements:

Coverage:	Broad
Throughput:	~1-10 Mbps
Latency:	Not critical

Key Aspects of the HAPS Architecture

Direct-to-Device: HAPS Vs. Satellite



In the past two years, a number of initiatives have emerged that aim to provide satellite-based communications directly to smartphone devices. These can be divided into the following categories:

- Services using the terrestrial spectrum, available to standard 4G/5G handsets (i.e. the phone does not know it is served by satellite), such as AST SpaceMobile or SpaceX “Direct to Cell” service, using LEO satellites.
- Services based on 3GPP Rel.17 NTN features using mobile satellite services (MSS) spectrum, such as Bullitt, and GEO satellites.
- Proprietary services, such as Apple’s emergency SOS feature.

In each case, the achievable data rates are rather modest due to the link budget constraints: the user device with limited power has to close the radio link with a satellite that is ~550 km to ~36,000 km far away. Therefore, they can generally support only low bandwidth services, such as text and emergency messaging.

HAPS, by comparison, has a much shorter distance to the user device, ranging from ~15 km to a few tens of km. That allows for high throughput services. Rather than limited text messaging, a HAPS service link can support voice calls, video streaming, webpage loading, video calls, and more — all to a standard smartphone.

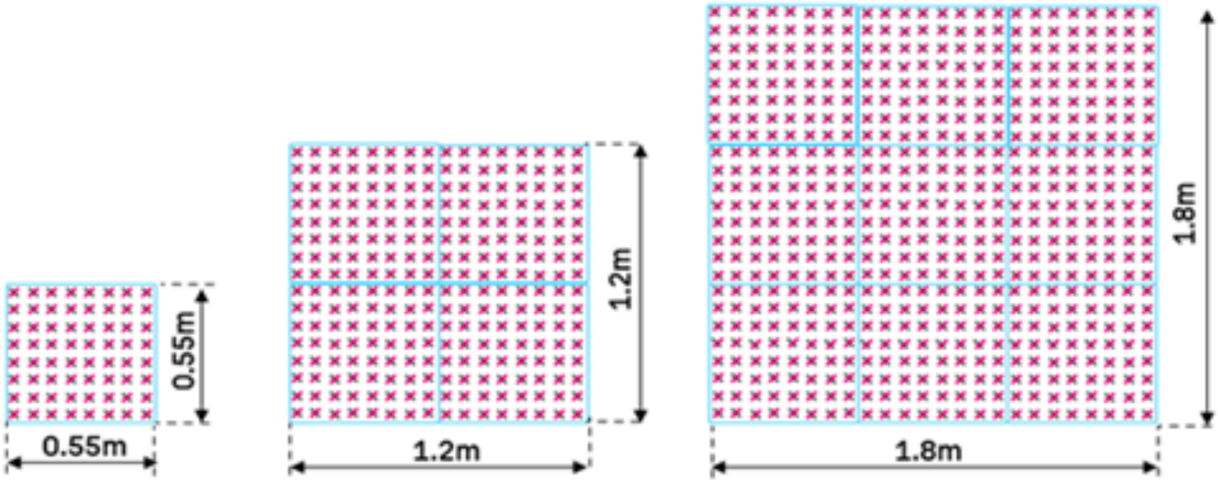
Typical Specifications of a HAPS Service Link

This section outlines the likely technical characteristics and key performance indicators for the direct-to-handset link of HAPS platforms. The complexity (and consequently cost) of a HAPS solution increases with the platform capacity as the platform is bound to certain size, weight and power (SWaP) constraints. Also, the optimal capacity may differ for different use cases. Therefore, different platform capability levels can be envisioned.

The following table captures the expected characteristics for low, medium, and high-capacity payloads.

	HAPS (Low Capacity)	HAPS (Medium Capacity)	HAPS (High Capacity)	Satellite (LEO)	Satellite (GEO)
Coverage	100 km in radius	100 km in radius	100 km in radius	500~1000 km in radius	Global coverage in total
Antenna Array Size (Example)	8 x 8 (dual pol.)	16 x 16 (dual pol.)	24 x 24 (dual pol.)	-	-
Communication Type	4G /5G	4G/5G	5G/6G	-	-
Throughput	10 ~500Mbps	500Mbps~5Gbps	5~50Gbps	100-500 Mbps/beam	10-200Mbps/beam
Weight	~30kg	30~50kg	100~150kg	-	-
Power Consumption	100W ~500W (service link)	500~1000W (service link)	1000~2000W (service link)	-	-
Overall Power Consumption	< 1 kW	< 3 kW	> 3 kW	-	-
Serving Beams (Cells)	< 20	< 100	> 100	100~1000 beams	100~1000 beams
Latency	~10 msec	~10 msec	~10 msec	~50 msec	~500 msec
Backhaul Capacity	< 1 Gbps	< 5 Gbps	> 5 Gbps	-	-
Cost per 1 HAPS/Satellite	$	$$	$$$	$$$	$$$$

The diagram below illustrates a possible antenna array layout for low, medium, and high-capacity levels for the 2 GHz frequency range. The relatively large size of high-capacity antenna poses additional challenges for integration to aerial platforms. Smaller arrays are easier to integrate but will provide smaller antenna gain and wider area per beam.



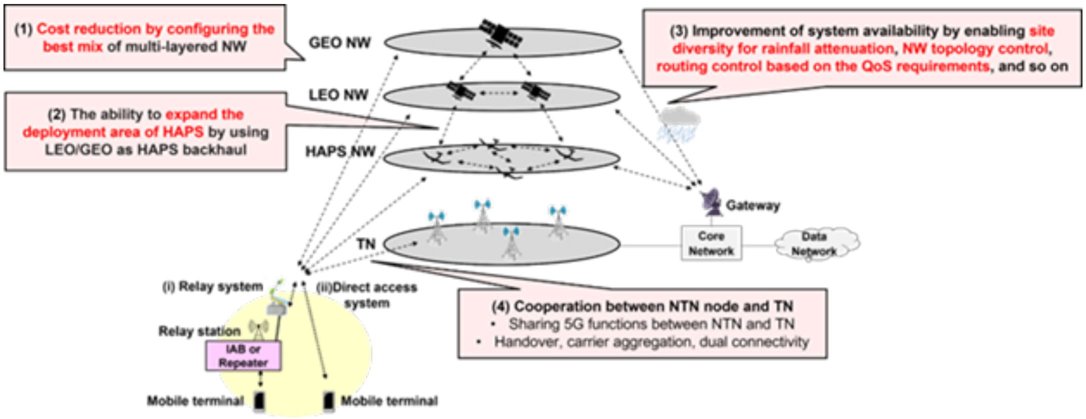
Network Topology: HAPS Coordination with LEO/GEO

The coordinated communication of several non-terrestrial platforms located between the stratosphere and GEO satellites can provide a resilient network backbone for several use cases. For example, these multi-layered non-terrestrial networks (ML-NTNs) can support earth observation, beyond-line-of-sight command and control use cases, as well as the extension of cellular connectivity, as detailed in previous sections of this paper.

Each layer of the ML-NTN is defined by the altitude above the Earth: the stratosphere (HAPS), the low earth orbit (LEO), the medium earth orbit (MEO), and the GEO layers. By connecting satellites and HAPS to the terrestrial 5G (or future 6G) core network, a ML-NTN can support large scale and three-dimensional coverage. The ground network, satellite and HAPS cooperate to provide seamless communication according to the required service coverage area (including air, sea, and space) and the required communication speed and latency. The major advantages of a ML-NTN include:

1. Cost reduction: Satellites and HAPS are mixed appropriately according to the requirements of each use case.
2. The ability to expand the deployment area of HAPS by using satellites as HAPS backhaul: When building coverage with HAPS alone, the communication distance of the feeder link is limited to about 50~100 km.
3. Improvement of system availability by enabling site diversity for rainfall attenuation, network topology control, routing control based on the QoS requirements, and so on.
4. ML-NTNs could offer highly efficient coordination with terrestrial networks (TNs).

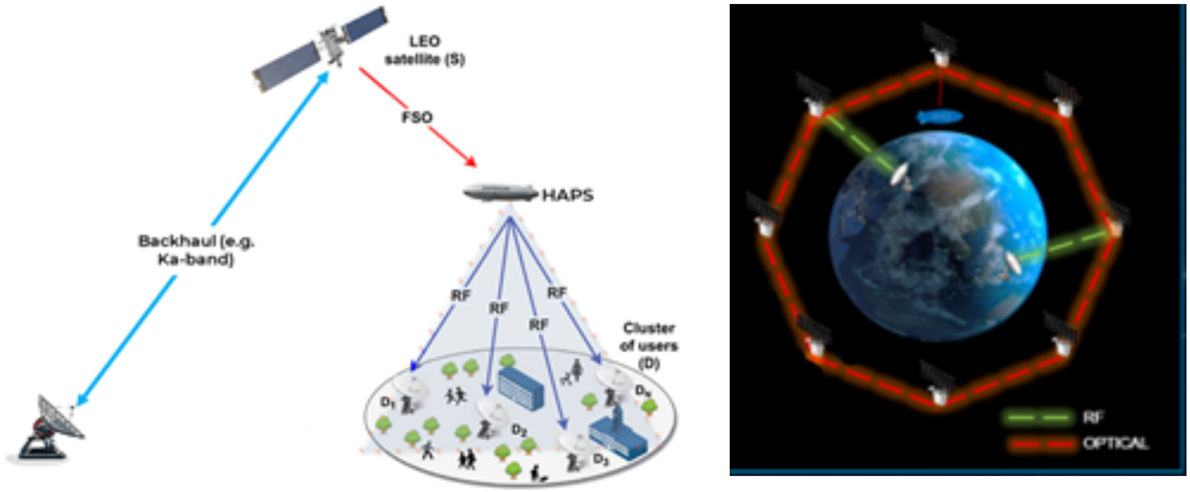
Two access systems to mobile terminals in NTNs are being considered: (i) relay access from satellites and HAPS through relay stations, and (ii) direct access from satellites and HAPS (see diagram). Using these systems, mobile terminals can be accessed in various ways depending on use cases and overall network optimization.



As an integral component of the 5G and 6G visions of ML-NTNs, HAPS can play a critical role in providing a ML-NTN backhaul backbone in coordination with LEO/GEO satellites. The scenarios underpinning ML-NTN backhauling — HAPS-satellite-ground (HSG) and HAPS-satellite-HAPS-ground (HSHG) — are detailed below. A common feature of these scenarios is the fact that HAPS lacks direct backhaul access to the core or operator network and would instead rely on the satellite for indirect backhaul access. This lack of access to a direct backhaul could be for several reasons, such as the size, weight, and power (SWaP) limitation of the HAPS platform. In the case of heavier than air HAPS, the lack of a spectrum license or temporary movement of the HAPS beyond the line of sight of its dedicated ground gateway could be a contributing factor.

Scenario One: HSG Backhaul

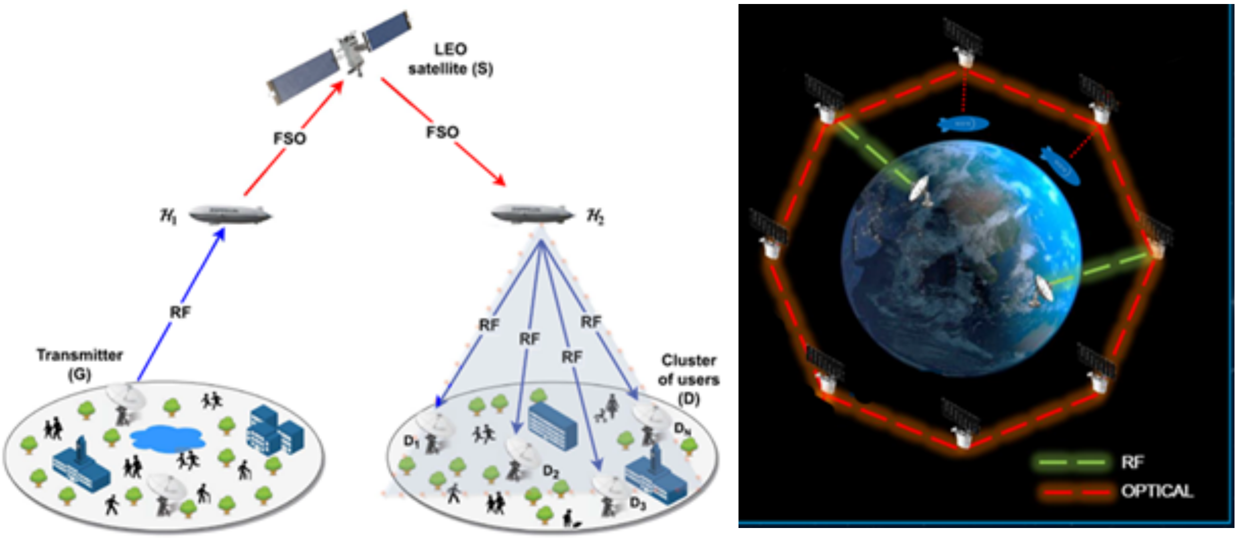
In this scenario, the HAPS is backhauling user traffic from service links to the core or operator network via a partner satellite. The HAPS-satellite link is ideally a laser (FSO) link, as it is close to free space. The satellite-ground link is a standard microwave (e.g., Ka-band) link. The partner satellite can be a standalone satellite, or a constellation of satellites as depicted in the image to the right. In both cases, the satellite links are wide-band (several GHz) high-capacity links.



HSG Backhaul scenario with one satellite (left) and multi-satellite connection (right).

Scenario Two: HSHG Backhaul

In this scenario, a fleet of coordinated HAPS provides services to users, where the service is coordinated across the HAPS fleet supposedly using inter-HAPS mesh links. However, for various reasons, the inter-HAPS mesh links can be broken. In this case, the different HAPS can maintain the mesh links indirectly through a partner satellite system. Similar to the HSG scenario, the satellite backhaul could be provided by a single satellite or a constellation of satellites. In both cases, the satellite links are wide-band (several GHz) high-capacity links.



HSHG backhaul scenario with one satellite (left) and multi-satellite connections (right).

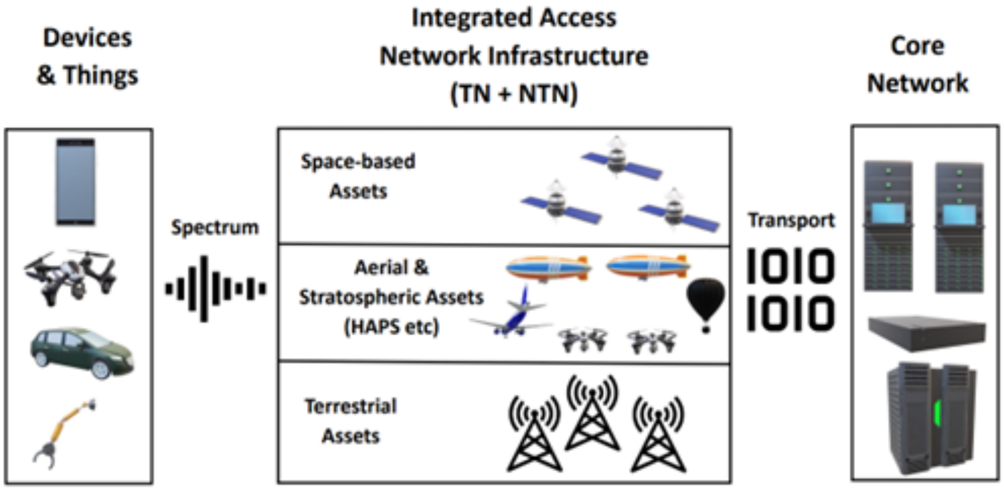
Integrated Access Network Infrastructure (IANI)

An integrated terrestrial and non-terrestrial access network architecture (IANI) encompasses three main platform infrastructure components — space, aerial/stratospheric, and terrestrial. The IANI hosts payloads and nodes performing various access network functions. The diagram below provides a unified or integrated view of the access network infrastructure comprising both terrestrial and non-terrestrial assets. The logical and physical delineation of the integrated access network itself remains valid, but abstracted in this infrastructure-based view.

This section offers an infrastructure-only view of the integration of the terrestrial and non-terrestrial network infrastructure. This view is essential to understanding each asset's unique technical and operational capabilities and contribution to the IANI concept. HAPS can play an important role in deploying a successful IANI system.

The 5G core network was designed to work seamlessly with more than one access technology, both 3GPP-defined and non-3GPP. The future 6G core should also support multiple access networks implemented over a seamlessly integrated access network infrastructure. The IANI concept is agnostic to access technologies or specific network functions or protocols: it is an abstracted description focusing on the access infrastructure.

Devices can attach to the network via the IANI and have access to the core network and the internet or other packet data networks. This scenario can only be possible when all three asset classes are integrated. The description of the IANI abstracts the specific location or distribution of network functions on the assets — for example, NTNs can be implemented as transparent or non-transparent (regenerative). Regardless of the mode of implementation, the NTN network functions have to be implemented on an airborne or space-borne infrastructure or platform. In the case of the regenerative mode, more functions and processing have to be performed onboard the satellite or HAPS (effectively a “flying” base station).



HAPS makes specific contributions to the overall success of deployment and implementation of IANI. An integrated access network architecture is essential for universal and ubiquitous connectivity. A user or device must be able to connect to the core network via this IANI regardless of what specific infrastructure is providing the access.

Sample Link Budget Calculation for Coverage over a Disaster Area

This section considers the link budget for a reference scenario involving the provision of communication services over a weather-stricken area using HAPS. As discussed in an earlier section, this scenario is set to become increasingly relevant mainly due to climate change and the effects of rapid urbanization.

Providing communications in areas with a significant weather event presents some challenges to any communication system, since the transmissions need to penetrate hydrometeor layers (clouds, rainfall areas, etc.) that decrease the signal strength through absorption and other mechanisms. Ensuring stable and reliable communications in weather-stricken areas is vital for the coordination of rescue and evacuation efforts.

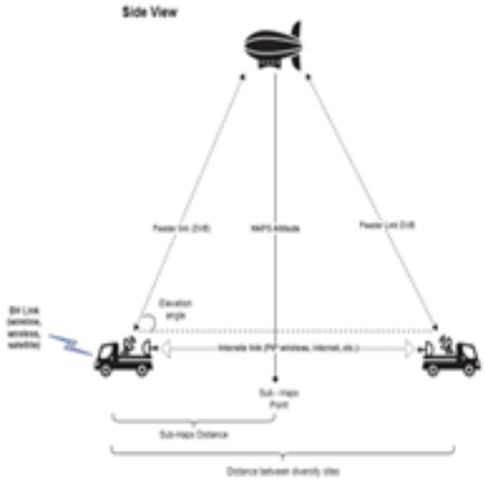
The Appendix to this paper provides a sample link budget calculation and describes the recommended communication setup, based on a site diversity configuration (explained below) with automatic fallback that can enable high-reliability communications as needed in such disaster areas. The sample calculation shows that, in the 39 GHz band, using site diversity, a link with system availability of 99.9% per annum is achievable with terminals as small as 0.85 meter. The estimated DC power consumption of the onboard terminal should be below 200 watts. The configuration for enabling the establishment of a stable high-speed feeder link to a HAPS after a massive outage due to a weather event is feasible but requires site diversity to achieve the required system availabilities, inter-site communications and backhaul communications.

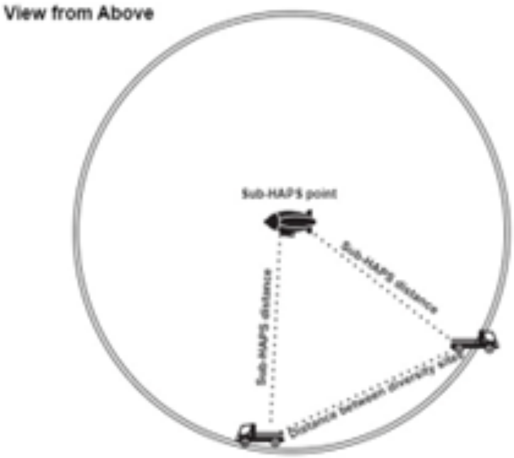
Note, that to provide single link availability of 98% and a practical implementation, the following considerations are important:

- To enable mobility and optimal location of feeder link (FL) terminals, they need to be small enough to facilitate easy transportation. For example, a 0.85-meter dish that could be installed on a small truck.
- The FL terminal should be weather-tolerant, so a radome must be used to protect the equipment.
- The FL terminal should be located away from an active weather event for safety reasons and connectivity purposes.
- The FL terminal(s) should be located in an area where it can connect to the internet either directly or via backhaul.

Site Diversity Configuration

A site diversity configuration comprises two different feeder link terminals, interconnected through a point-to-point link. One of the terminals is also connected to the internet via a local point of presence or a backhaul link. The terminals are configured in an automatic failover setup, so if the active link to the HAPS suffers from a weather-related fade, the standby link is automatically activated to maintain the required level of link availability. This setup is more cost-effective and provides higher reliability than a single link setup that can suffer from a weather-related fade in areas with rain and other phenomena. The following picture shows the side view and the view from above of the site diversity configuration.





Join us in Our Work

All companies interested in the HAPS ecosystem are encouraged to become HAPS Alliance members. Alliance membership levels — Principal, General, and Supporter — are open to organizations in any industry sector. Principal and General Members have the opportunity to become involved in various membership initiatives, including working groups and collaboration with other HAPS Alliance members to work on technology components and use cases for enabling a smarter world.

About the HAPS Alliance

The HAPS Alliance is an industry association of High Altitude Platform Station (HAPS) industry leaders that include telecommunications, technology, defense, aviation, and aerospace companies, as well as public and educational institutions. United by a mission to unlock the stratosphere to enhance connectivity and sensing services for civilian and government applications globally, the Alliance is working to accelerate the development and commercial adoption of HAPS technology by promoting and building industry-wide standards, interoperability guidelines and regulatory policies in the telecommunication, defense and aviation industries. For more information, please visit https://hapsalliance.org

Appendices

Additional Assumptions

The following assumptions are used in the attenuation and link budget calculations shown in the following sections:

- Feeder link uses V band frequencies (38.75 GHz mid frequency)
- For attenuation calculation, we have used three different reference sites representing three distinct rain regime cases (three for the attenuation calculation and one for the link budget):
    - Naha, Japan: (86 mm/h R0.01)
    - Tokyo, Japan: (56 mm/h R0.01)
    - Brussels, Belgium: (30 mm/h R0.01)
- HAPS Altitude of 20 km
- Practical fade limit for link budget: – 12 dB (estimated parameter that can be adjusted)
- Assumed link system availability with site diversity: – 99.9%
- Required feeder link throughput: – 5Gbps
- Assumed onboard power consumption:
    - Onboard RF front-end consumption: up to ~100 Watt
    - Onboard modem consumption: up to ~100 Watt

Sample Atmospheric Attenuation Calculation per Different Site Diversity Configurations

In areas with active weather, not every site diversity configuration can close the link budget (per the assumed fade limits stated in prior section) or yield the required link availability.

The following is a table with attenuation estimations per different site diversity geometrical configurations. Problematic areas are highlighted in gray cells and red fonts (areas in which the attenuation is larger than 12dB).

38.75 GHz U/L Total Atmospheric Attenuation dB										
Link Test Cases	FL Relative Location	Elevation=20° SubHAPS Distance= 54 Km			Elevation=30° SubHAPS Distance= 34 Km			EL=40°; SubHAPS Dist= 24 Km		
	City	Naha	Tokyo	Brussels	Naha	Tokyo	Brussels	Naha	Tokyo	Brussels
	mm/h R0.01	86	56	30	86	56	30	86	56	30
Single Site Avail. for 99.9% SD	98% @ 20 Km	23.2	17.3	7.6	17.2	12.8	5.5	14.4	10.7	4.2
	97% @ 30 Km	19.4	14.2	6.4	14.3	10.5	4.6	11.8	8.7	3.4
	96% @ 50 Km	16.7	12.1	5.6	12.2	8.9	4.0	10.2	7.3	2.9
38.75 GHz D/L Total Atmospheric Attenuation dB										
Link Test Cases	FL Relative Loc	EL=20°; SubHAPS Dist= 54 Km			EL=30°; SubHAPS Dist= 34 Km			EL=40°; SubHAPS Dist= 24 Km		
	City	Naha	Tokyo	Brussels	Naha	Tokyo	Brussels	Naha	Tokyo	Brussels
	mm/h R0.01	86	56	30	86	56	30	86	56	30
Single Site Avail. for 99.9% SD	98% @ 20 Km	24.2	18.2	8.3	18.6	14.1	6.4	15.9	12.1	5.0
	97% @ 30 Km	20.3	15.1	7.0	15.6	11.7	5.3	13.3	10.0	4.0
	96% @ 50 Km	17.7	12.9	6.1	13.5	10.0	4.6	11.6	8.5	3.4

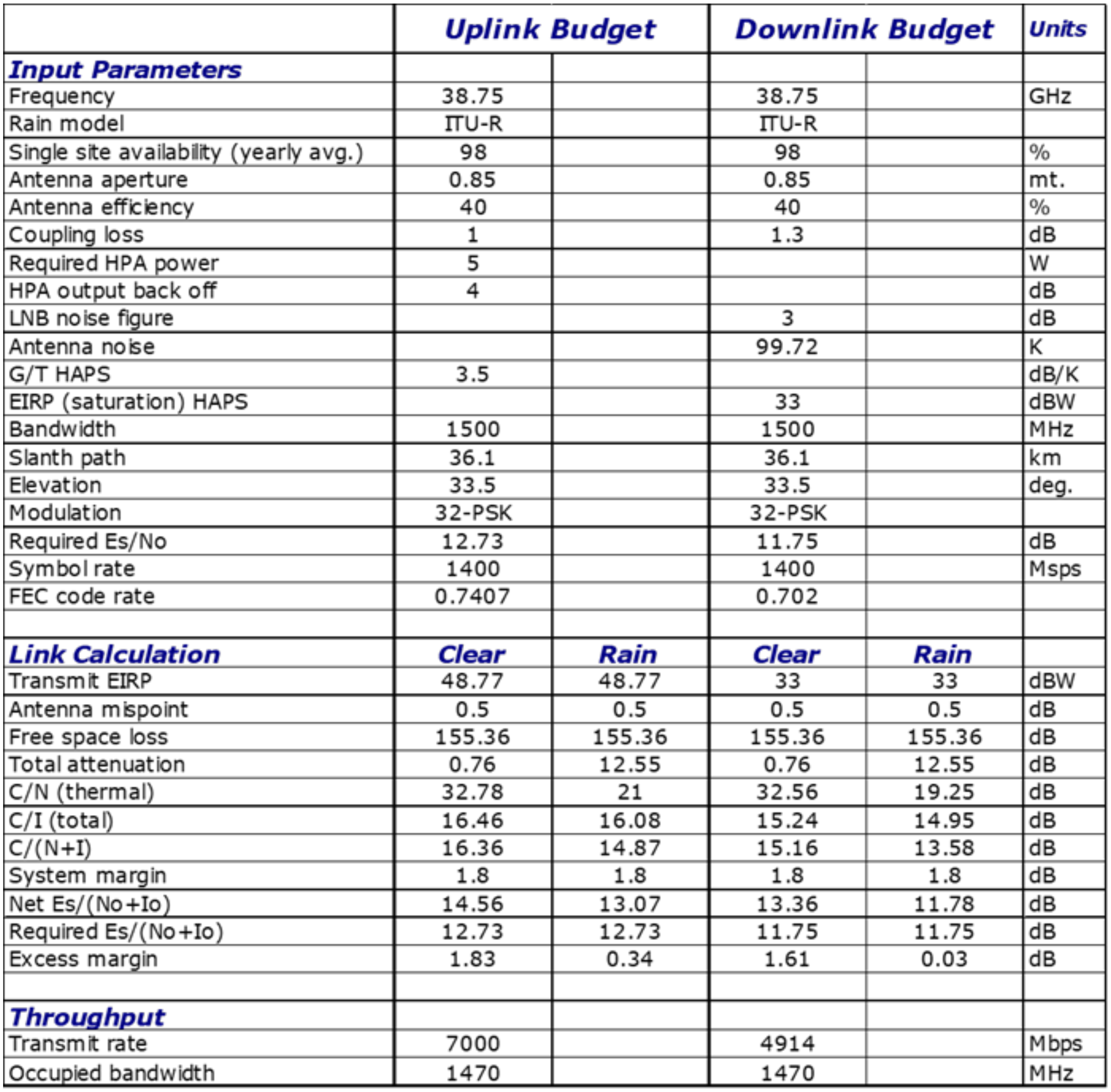
Notes:

- Estimated practical attenuation limit: – 12dB.
- Calculated with SM 10.5a total atmospheric attenuation.
- 38.75 GHz is the mid-frequency of the HAPS 39 GHz range.
- SubHAPS distance is distance from the point directly below the HAPS to the terminal.
- The different geometrical configurations (as shown in the diagrams below) come to show the impact of terminal distance and elevation.
- Test locations (cities) were selected to represent three types of Rain-zones (R0.01).
- SD: site diversity. Joint site diversity availability target assumed to be 99.9%.

- The single-site availability targets per SD distance were taken from simplified ITU model.
- We can see that if we assume a practical attenuation limit of 12dB (a configurable parameter), then not all combinations of elevation, SD distance and SubHAPS distance are possible.

Link Budget (LB) Calculation Results

The following LB was calculated using SatMAster 3 for Tokyo reference point for both UL and DL:



	Uplink Budget		Downlink Budget		Units
Input Parameters					
Frequency	38.75		38.75		GHz
Rain model	ITU-R		ITU-R		
Single site availability (yearly avg.)	98		98		%
Antenna aperture	0.85		0.85		mt.
Antenna efficiency	40		40		%
Coupling loss	1		1.3		dB
Required HPA power	5				W
HPA output back off	4				dB
LNB noise figure			3		dB
Antenna noise			99.72		K
G/T HAPS	3.5				dB/K
EIRP (saturation) HAPS			33		dBW
Bandwidth	1500		1500		MHz
Slanth path	36.1		36.1		km
Elevation	33.5		33.5		deg.
Modulation	32-PSK		32-PSK		
Required Es/No	12.73		11.75		dB
Symbol rate	1400		1400		Msps
FEC code rate	0.7407		0.702		
Link Calculation	**Clear**	**Rain**	**Clear**	**Rain**	
Transmit EIRP	48.77	48.77	33	33	dBW
Antenna mispoint	0.5	0.5	0.5	0.5	dB
Free space loss	155.36	155.36	155.36	155.36	dB
Total attenuation	0.76	12.55	0.76	12.55	dB
C/N (thermal)	32.78	21	32.56	19.25	dB
C/I (total)	16.46	16.08	15.24	14.95	dB
C/(N+I)	16.36	14.87	15.16	13.58	dB
System margin	1.8	1.8	1.8	1.8	dB
Net Es/(No+Io)	14.56	13.07	13.36	11.78	dB
Required Es/(No+Io)	12.73	12.73	11.75	11.75	dB
Excess margin	1.83	0.34	1.61	0.03	dB
Throughput					
Transmit rate	7000		4914		Mbps
Occupied bandwidth	1470		1470		MHz

Feeder Link Terminal (Ground and Onboard): Assumptions

The following table provides the assumptions regarding the system parameters for the ground and onboard feeder link terminals.

Feeder Terminal - ROM Estimate

Freq.	Function	Diameter	Efficiency	Radome	Scan Loss**	G/A	Eff Gain	P - Net Power *	G/T	EIRP
GHz		m	%	db	db	db	dbi	W	db/K	dbW
38.76	FL Tx up	0.85	40.0	1.0	0.0	53.2	45.8	2.0	NA	48.8
38.74	FL Rx dn		40.0	1.0	0.0	53.2	45.8	NA	19.0	NA

**Pedestal Terminal

*P = Psat - OBO

System Temperature - ROM Estimate Tref= 290 °K

F GHz	Direction	LN NF db	TIn °K	Tbg°K	Radom db	Trad° K	Tsys°K
38.74	Dn-OnGnd	3	288.6	130	1.0	59.6	478.3
38.76	Up-OnBrd	4	438.4	400	1.0	59.6	898.1

OnBoard Terminal - ROM Estimate

F	Function	Diameter	Efficiency	Radome	Scan Loss**	G/Aeff	Eff Gain	P - Net Power *	G/T	EIRP
GHz		m	%	db	db	db/m²	dbi	W	db/K	dbW
38.74	FL Tx dn	0.30	40.0	1.0	4.0	53.2	32.7	2.0	NA	35.7
38.76	FL Rx up		40.0	1.0	4.0	53.2	32.7	NA	3.2	NA

**Flat-Horizontal Terminal

*P = Psat - OBO

PA DC Calculation

Net RF P	OBO	Nom RF P	Eff	DC Power
W	db	W	%	W
2.0	4.0	5.0	15.0	33.5

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