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**APT REPORT ON**

**HAPS INDUSTRY AND ECOSYSTEM FOR**

**BROADBAND CONNECTIVITY**

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**APT REPORT ON**

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**Abbreviation and Definition**

3G : Third-Generation

3GPP : Third-Generation Partnership Project

ARQ : Automatic Repeat reQuest

CTMS : Collaborative Traffic Management in the Stratosphere

FSO : Free-Space Optic

HAPS : High Altitude Platform Station

HIBS : HAPS as IMT Base Station

ICAO : International Civil Aviation Organization

ICT : Information and Communication Technology

IHL : Inter-HAPS Links

IMT : International Mobile Telecommunications

IP : Internet Protocol

ITU : International Telecommunication Union

LMIC : Low- and Middle-Income Countries

MIMO : Multiple Input Multiple Output

NASA : National Aeronautics and Space Administration

NTN : Non-Terrestrial Network

OSI : Open Systems Interconnection

PFD : Power Flux Density

PSTN : Public Switched Telephone Network

RF : Radio Frequency

RR : Radio Regulations

SDG : Sustainable Development Goal

TT&C : Telemetry, Tracking, and Command

UAS : Unmanned Aircraft System

UAV : Unmanned Aerial Vehicles

UN : United Nations

WTDC : World Telecommunication Development Conference

1. **Introduction**

An area is called the telecommunication underserved areas is due to inadequate supporting infrastructure, difficult terrain, illiteracy, high cost of installation of information and communication technology (ICT) infrastructure and policy issues [1], for example, in rural areas are often underserved due to their remote location and low population density causing the penetration rate for such as the PSTN subscribers is twenty per cent below the national PSTN penetration rate [2].

Based on the State of Broadband 2022 by the Broadband Commission [3], the latest ITU data show that uptake of the Internet accelerated during the pandemic. In 2019, 54 per cent of the world’s population were using the Internet with this figure growing to an estimated 66 per cent in 2022, representing 5.3 billion people. In 2020, the first year of the pandemic, the number of Internet users grew by over 10 per cent, the largest increase in a decade; in LMICs Internet use went up 15 per cent. A significant part of this growth was driven by the need to use quarantine-related applications such as videoconferencing for work and education as well as online shopping, access to public services and remote health consultation but yet potential of the Internet for social and economic good remains largely untapped: one-third of humanity (2.9 billion people) remains offline and many users only enjoy basic connectivity as described in the ITU Global Connectivity Report 2022 [4].

As one-third of the world’s population remains offline and many among the online population are not meaningfully connected. The “missing link” has morphed into multiple digital divides, across and within countries, between men and women, between youth and older persons, between cities and rural areas, between those who enjoy a fibre connection and those who struggle on a spotty 3G connection.

Linking everyone is no longer enough. Universal and meaningful connectivity, the possibility for everyone to enjoy a safe, satisfying, enriching, productive, and affordable online experience, has become the new imperative for the 2020-2030 decade.

In the frame to close the gap or missing link, three challenges have emerged:

* Closing the coverage gap: Even though 95 per cent of the world population is now within range of a mobile broadband network, at least 390 million people have no possibility to connect to the Internet.
* Closing the usage gap: One in three individuals who could go online choose not to, mainly due to prohibitive costs, lack of access to a device, and/or lack of awareness, skills, or purpose.
* Achieving universal and meaningful connectivity: This means upgrading connectivity from basic to meaningful for all.

Evidence suggests that introducing people to the Internet usually entices them to stay online. Based on activities people reported, use of the Internet leads to an improved social life, with the use of social networks, making Internet calls and streaming video the most common activities.

Sebuah gambar berisi grafik

Deskripsi dibuat secara otomatis

Figure . Connectivity and Human Development

* 1. **Background**

The High-altitude, long endurance flight is studied since at least 1983, and demonstrator programs followed since 1994. Hydrogen and solar power were proposed as alternatives to conventional engines and will operate above commercial air transport and wind turbulence, at high altitudes, drag as well as lift are reduced [5]. In 1983, a Preliminary Study of solar powered aircraft and Associated Power Trains for the NASA by Lockheed Martin, as a long endurance flight could be compared to suborbital spacecraft. In 1984, the Design of Long Endurance Unmanned Airplanes Incorporating Solar and fuel cell propulsion report was also published, and in 1989, the Design and experimental results for a high-altitude, long-endurance airfoil report proposed applications as a radio relay for weather monitoring or cruise missile targeting.

As shown in Table 1, the high-altitude and long-endurance use for the telecommunication purposes is High Altitude Platform Station (HAPS) which has been defined and studied by ITU since mid-1990s. Nevertheless. HAPS now has become more viable and feasible due to technological advances in solar panel efficiency, battery energy density, lightweight composite materials, autonomous avionics, and antennas. HAPS has the advantages of higher capacity, lower latency, and better penetration among Non-Terrestrial Network (NTN) solutions, due to the lower altitude to the earth surface. Therefore, HAPS would not only serve basic communication services like messaging and voice, but also provide richer services such as mobile internet and even entertainment. HAPS systems can potentially be used to provide both fixed broadband connectivity for end-users and transmission links between the mobile and core networks used for backhauling traffic that would further enable the wireless broadband deployment in remote areas, including in mountainous, coastal, and desert areas. In some situations, HAPS may be rapidly deployed for disaster recovery communications, particularly because the use of inter-HAPS links allows the provision of services with minimal ground network infrastructure – for example, for backing up terrestrial networks damaged by disasters. Therefore, HAPS would contribute significantly to bridging the digital divide, efficiently complementing other technologies, and enabling countries to be connected directly, quickly, and reliably as mentioned in WTDC Resolution 37 (Rev. Kigali, 2022). Furthermore, HAPS contributes to the attainment of UN Sustainable Development Goal (SDG) 9 (industry, innovation, and infrastructure) as well as other SDGs by allowing for greater broadband connectivity and telecommunication services, particularly in rural and remote areas [6].

Table . Comparison Among Proposed HAPS Concepts and Technologies

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Model** | **1st Flight** | **Span** | **Weight** | **Payload** | **Altitude** | **Endurance** | **Status** |
| **HTA/UAV Solar Powered** | | | | | | | |
| AeroVironment Pathfinder [7] | 1993 | 29.5 m | 252 kg | 45 kg | 21,800 m | 12 hours | N/A |
| AeroVironment Pathfinder plus [7] | 1998 | 36.3 m | 315 kg | 67,5 kg | 24,445 m | N/A | N/A |
| AeroVironment Helios [8] | 1999-09 | 75 m | 929 kg | 329 kg | 29,524 m | goal: >24 hours | 2003 crash |
| Airbus Zephyr [9] | 2005-12 | 25 m | 75 kg | 5 kg | 23,200 m | 64 days | 2024 planned commercial |
| Titan Aerospace Solara [10] | 2015-05 | 50 m | N/A | 30 kg | 160 m | 4 min | 2017 shut down |
| KARI EAV-3 [11] | 2015-08 | 20 m | 66 kg | N/A | 22,000 m | 53 hours | N/A |
| UK OS Astigan A3 [12] | 2016 | 38 m | 149 kg | 25 kg | 20,000 m | Target 90 day | 2021 project ended |
| Facebook Aquila [13] | 2016-06 | 40 m | 424 kg | N/A | 660 m | 90 min | 2018 project halt |
| UAVOS ApusDuo [14] | 2018-10 | 15 m | 43 kg | 2 kg | 18,000 m | goal: year-round | N/A |
| AeroVironment HAPSMobile [15] | 2019-09 | 78 m | N/A | N/A | 19,100 m | 20 hours | N/A |
| BAE Systems PHASA-35 [16] | 2020-02 | 35 m | 150 kg | 15 kg | goal: 21,000 m | 72 hours | N/A |
| Swift Engineering SULE [17] | 2020-07 | 22 m | 82 kg | 6.8 kg | goal: 21,000 m | N/A | N/A |
| **HTA/UAV Hydrogen Fueled** | | | | | | | |
| Stratospheric Platforms [18] | 2020-10 | 60 m | N/A | 140 kg | 14,000 m | 9 days | N/A |
| **Airship** | | | | | | | |
| SwRI HiSentinel [19] | 2005-11 | 44.5 m | N/A | 27.2 kg | 23,000 m | 5 hours | N/A |

Note: N/A is Not Available

In terms of frequency usage, the various frequency bands are already identified for HAPS in Radio Regulations (RR) as follows (See section 2 for detail).

* HAPS in the Fixed Services – In the WRC-19, 21 GHz, 26 GHz and 38 GHz bands were identified in addition to existing 6 GHz, 28 GHz, 31 GHz and 47 GHz bands.
* HIBS (HAPS as IMT base station) – In the WRC-23, 700-900 MHz, 1.7 GHz and 2.6 GHz bands were identified in addition to existing 2 GHz band.

It means that the international rule enabling the flexible use of frequency bands in different countries and regions when introducing HAPS has already been readied [47].

1. **Operational and Spectrum Aspects**

The HAPS general frequency spectrum allocation for the Region 1, 2 and 3 is provided in Article 5 of the ITU Radio Regulation [20]. The regulatory provision of HAPS for notification is provided by the Article 11 supported by the Appendix 4 and 10. The following table provides the summary of the HAPS spectrum allocation.

*Table 2. HAPS Spectrum Allocation by Article 5 of ITU Radio Regulation Edition [2024]*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Frequency** | **Area** | **Intended Use** | **Link type** | **Resolution** |
| 694-960 MHz | Region 1 | Mobile Service, HAPS as IMT base station (HIBS)(6) | mobile station-to-HIBS direction / HIBS-to-mobile station(1) (2) | Resolution **213 (WRC-23)** |
| 698-960 MHz | Region 2 | Mobile Service, HAPS as IMT base station (HIBS)(6) | mobile station-to-HIBS direction / HIBS-to-mobile station(1) (2) | Resolution **213 (WRC-23)** |
| 698-960MHz | Australia, Maldives, Micronesia, Papua New Guinea, Tonga and Vanuatu | Mobile service, HAPS as IMT base station (HIBS)(6) | mobile station -to- HIBS direction / HIBS-to-mobile station direction(1) (3) | Resolution **213 (WRC-23)** |
| 703-733 MHz,  758-788 MHz,  890-915 MHz,  935-960 MHz | China, India, Indonesia, Japan, Korea (Rep. of), Malaysia, the Philippines and Thailand | Mobile service, HAPS as IMT base station (HIBS)(6) | mobile station -to-HIBS direction / HIBS-to-mobile station direction(1) (3) | Resolution **213 (WRC-23)** |
| 1 710-1 980 MHz,  2 010-2 025 MHz,  2 110-2 170 MHz | Region 1, 3 | Mobile service, HAPS as IMT base station (HIBS) to provide (IMT)(6) | mobile station -to-HIBS direction / HIBS-to-mobile station direction(1) (4) | Resolution **221 (Rev.WRC-23)** |
| 1 710-1 980 MHz,  2 110-2 160 MHz | Region 2 | Mobile service, HAPS as IMT base station (HIBS)(6) | mobile station -to-HIBS direction / HIBS-to-mobile station direction(1) (4) | Resolution **221 (Rev.WRC-23)** |
| 2 500-2 690 MHz | Region 1, 2 | Mobile service, HAPS as IMT base station (HIBS)(6) | mobile station -to-HIBS direction / HIBS-to-mobile station direction(1) (5) | Resolution **218 (WRC-23)** |
| 2 500-2 655 MHz | Region 3 | Mobile service, HAPS as IMT base station (HIBS)(6) | mobile station -to-HIBS direction / HIBS-to-mobile station direction(1) (5) | Resolution **218 (WRC-23)** |
| 6 440-6 520 MHz | Australia, Burkina Faso, Cote d’Ivoire, Mali and Nigeria | Gateway links for high-altitude platform station (HAPS) within the country territory | HAPS-to-ground direction | Resolution 150 (WRC-12) |
| 6 560-6 640 MHz | ground-to-HAPS direction |
| 6 560-6 640 MHz | Region 2 | Fixed Service | ground-to-HAPS direction | Resolution 165 (WRC-19) |
| 21.4-22 GHz | Region 2 | Fixed Service | ground-to-HAPS direction / HAPS-to-ground direction | Resolution 165 (WRC-19) |
| 24.25-25.25 GHz | Region 2 | Fixed Service | ground-to-HAPS direction / HAPS-to-ground direction | Resolution 166 (WRC-19) |
| 25.25-27.5 GHz | Region 2 | Gateway links | ground-to-HAPS direction in the frequency band 25.25-27.0 GHz  HAPS-to-ground direction in the frequency band 27.0-27.5 GHz | Resolution 166 (WRC-19) |
| 27.9-28.2 GHz | 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 | Fixed Service, may also be used by HAPS within the country territory | HAPS-to-ground direction and shall not cause harmful interference to, nor claim protection | Resolution 145 (Rev.WRC-19) |
| 31-31.3 GHz | Global | Fixed Service | ground-to-HAPS direction / HAPS-to-ground direction | Resolution 167 (WRC-19) |
| 38-39.5 GHz | Global | Fixed Service | HAPS-to-ground direction, the HAPS ground station shall not claim protection from stations in the fixed, mobile and fixed-satellite services | Resolution 168 (WRC-19) |
| 47.2-47.5 GHz and 47.9-48.2 GHz | Global | Fixed Service | ground-to-HAPS direction / HAPS-to-ground direction | Resolution 122 (Rev.WRC-19) |

Note to the Table:

(1) HIBS shall not claim protection from existing primary services. No. **5.43A** does not apply.

(2) The frequency bands 694-728 MHz, 830-835 MHz and 805.3-806.9 MHz are limited to use for reception by HIBS.

(3) The frequency bands 698-728 MHz and 830-835 MHz are limited to use for reception by HIBS.

(4) The frequency bands 1 710-1 785 MHz in Regions 1 and 2, and 1 710-1 815 MHz in Region 3 are limited to use for reception by HIBS, and the frequency band 2 110-2 170 MHz is limited to use for transmission from HIBS.

(5) The frequency bands 2 500-2 510 MHz in Regions 1 and 2, and 2 500-2 535 MHz in Region 3 are limited to use for reception by HIBS.

(6) Resolutions 213 (WRC-23), 218 (WRC-23), and 221 (Rev.WRC-23) in the Radio Regulations (RR) define “HIBS: High-altitude platform station as IMT base station. The conditions in this Resolution refer to these platforms operating between 18 km and 25 km.”

1. **Industry Status**

The discussion in this section focuses on aspects of the air segment and the ground segment of HAPS which with explanations, especially updates from the industry will be able to provide a better picture related to the HAPS ecosystem.

The HAPSAlliance is a global industry consortium dedicated to advancing the development and adoption of HAPS. These systems include stratospheric aircraft or balloons, typically operating at altitudes between 18 km and 50 km.

Founded in 2020, the HAPS Alliance brings together technology companies, telecom operators, and aerospace organizations to foster collaboration and innovation in high-altitude platform systems. Its mission includes establishing industry standards, advocating for supportive regulatory frameworks, and accelerating the deployment of HAPS technologies to address global connectivity gaps.

HAPS Alliance member companies collaborate with authorities worldwide to promote the benefits of HAPS, build a cooperative ecosystem, develop common product specifications, and advance the standardization of HAPS network interoperability.

The HAPS Alliance has published several white papers addressing various aspects of HAPS:

1. **High Altitude, Higher Ambitions** (May 1, 2020): This white paper outlines the multi-billion-dollar market opportunity in the stratosphere, covering telecommunications, earth observation, and weather prediction. [49]
2. **Driving the Potential of the Stratosphere** (August 5, 2021): This white paper provides key industry statistics and insights from HAPS Alliance member companies, highlighting the potential of stratospheric operations. [50]
3. **Bridging the Digital Divide with Aviation in the Stratosphere** (December 14, 2021): This white paper discusses flight test results that demonstrate HAPS technology's potential to enhance connectivity and support applications such as earth observation and disaster management. [25]
4. **HAPS Operation Using Attended Autonomous Fleet Systems** (April 12, 2022): This white paper introduces the concept of Collaborative Traffic Management for the Stratosphere (CTMS), enabling safe and scalable operations of HAPS vehicles as attended autonomous fleets. [30]
5. **Guidelines for Payload Operation in the Stratosphere** (December 13, 2022): This white paper provides integration and environmental guidelines for payload providers developing equipment for HAPS vehicles operating in the stratosphere. [51]
6. **Acceptable Levels of Risk for HAPS** (January 31, 2024): This white paper explores the challenges of setting safety metrics for HAPS, proposing third-party-centric metrics that consider individual and collective risk limits for both ground and air risks. [52]
7. **HAPS Certification Pathways** (February 8, 2024): This white paper identifies key regulatory challenges in obtaining approval for commercial HAPS operations and recommends actions to facilitate their safe and efficient integration into global airspace. [53]
8. **Creating an Enabling Regulatory Environment for HAPS Deployment** (May 16, 2024): This white paper provides a comprehensive overview of regulatory recommendations for HAPS to support the stratospheric ecosystem. It includes the latest information, such as the expansion of HAPS service-links following WRC-23, to assist governments in implementing appropriate HAPS regulations within their national frameworks. [47]
9. **HAPS Reference Architecture Series: Cell Towers in the Sky** (October 28, 2024): This white paper discusses the potential of HAPS networks to bridge connectivity gaps, emphasizing their unique benefits—flexibility, scalability, and cost efficiency—over terrestrial and satellite networks." [54]
10. **HAPS Reference Architecture Series: HAPS Advantages in an Era of Satellite Connectivity** (April 15, 2025): This white paper outlines key use cases for HAPS, including providing connectivity in underserved areas, filling gaps in cellular networks, supporting emergency response, and extending coverage over oceans. [55]
    1. **The air segments**
11. HAPS platform and payload technology

The HAPS platform as briefly described in [21] as well as in Table 1 are the focus by all HAPS developers. The figure below illustrates the two HAPS platforms widely developed and tested.

Sebuah gambar berisi outdoor, pertunjukan udara

Deskripsi dibuat secara otomatis Sebuah gambar berisi outdoor, pesawat terbang, awan, transportasi

Deskripsi dibuat secara otomatis 

Figure . Examples of UAV Based HAPS Platform [27] [29] [31]

Sebuah gambar berisi transportasi, Perjalanan udara, Rekayasa dirgantara, pesawat udara

Deskripsi dibuat secara otomatis 

Figure . Examples of Airship Based HAPS Platform [26] [28]

Both examples definitely provide the structure stability, sufficient power supply and attitude control mechanism to assure the normal operation of the payload as well as to achieve the mission’s goal.

The HAPS payload technology is depending on the mission of the HAPS itself, however in general there are at least three missions which HAPS can be utilized:

* Telecommunication connectivity as backhaul and access, including HAPS as IMT Base Station and TV/Radio broadcaster.
* Earth observation or remote sensing, of which HAPS could carry some sensors.
* Geo-localization.

Each mission requires a specific payload design, including the antenna and its transmission beam model.

1. Operation flight duration

HAPS operation flight duration depends to many factors that affect how long the platform(s) could remain at the stratospheric layer, from hours to years, such as:

* the mission of operation,
* the flight pattern plan,
* the environmental condition such as the high wind,
* the type of the HAPS platform

1. Energy supply technology

The HAPS energy supply technology is described in Table 1 and [21] which mostly use energy supply technology of:

* Solar energy;
* Fuel cell;
* Lithium battery;
* Hydrogen energy.

1. Flight attitude control (TT&C) technology

The HAPS attitude control (TT&C) is similar to satellite system one, hence due to the low operation altitude of HAPS more TT&C centers are needed or can be relayed via satellite link. According to [30], the Collaborative Traffic Management in the Stratosphere or CTMS may be needed to manage the operation of multiple HAPS platform, multi operators and multi missions. Considering that HAPS can be operated on a cross border mode as illustrated below.

Sebuah gambar berisi teks, peta, diagram, garis

Deskripsi dibuat secara otomatis

Figure . National Representation of International Operations at Altitude Involving Multiple Operators

1. Maneuverability of the platform

The maneuverability of the HAPS platform is dynamic: they constantly replan and adjust (sometimes every minute to the observed condition and fleet optimization logic, which also depends on the platform technology such that the UAV (fixed-wing) based HAPS platform will fly in circular, elliptical, helicoidal, figure 8 or non-stationary patterns (e.g., search/scanning patterns), exploring an altitude range following a diurnal cycle. They may frequently adjust their “orbit trajectories,” target position and altitude to respond to network management optimization and environmental conditions.

1. HAPS operating altitude

HAPS is operated in the stratosphere, a layer of the atmosphere far above the clouds. This positioning ensures that HAPS is not affected by rain or snow and air currents have little influence. These characteristics enable the flight of a stratospheric platform to be more stable as compared to flight in other layers of the atmosphere [25].

Although the RR No.1.66A defines the operational altitude of HAPS as 20 to 50 km, HAPS is expected to operate flexibly at altitudes below 20 km in certain environments, such as those with insufficient solar radiation, or situations requiring rapid response to disasters.

The possibility of the operation below 20 km is considered in regulatory conditions for HIBS in the RR and in technical analysis on HAPS gateway-links in AWG Report as follows [47]:

* HIBS is defined as platforms operating at altitudes between 18 km and 25 km in WRC Resolutions **213 (WRC-23)**, **218 (WRC-23)**, and **221 (Rev.WRC-23)** in the RR (See Note to the Table 2).
* For HAPS gateway-links, according to the document APT/AWG/REP-127 [48], the results of technical studies show that “*HAPS operating at 18 km would not impact much to the incumbent services, thus alternative altitude for HAPS operation which differs from the identification in RR would be feasible under the authority of the administration who will operate HAPS.*”

1. Service coverage range

As described in the [21] service coverage range or radius is the function of the altitude, however service area may vary related to the mission and the antenna pattern plan. The traditional service coverage may range within 200 km of diameter with low power flux density (PFD). In order to increase the PFD and the capacity, ~~a~~ multi spot beams approach may be applied, considering that each beam size may vary from few kilometers to tenth of kilometers in diameter.

1. Telecommunications system

The telecommunication system used by HAPS consists of 2 sub-systems, the TT&C and the service (backhaul and access). The TT&C telecommunication system that control the HAPS attitude uses portion of the allocated spectrum for HAPS for the direct TT&C operation. For a non-direct TT&C, which may be relayed via satellite, it could use the leased satellite spectrum.

The telecommunication system for the HAPS service, for backhaul link it uses any allocated spectrum for HAPS in Table 2, meanwhile for the access link can use the spectrum allocated to HIBS or any allowed spectrum by the administration.

1. Antenna technology

The type of antenna technology on HAPS platform are:

* Antenna system for direct TT&C, for the function of telemetry and telecommand which requires a high gain antenna,
* Antenna system for backhaul service to connect to the gateway, which requires high gain antenna.
* Antenna system for access service, may requires less high gain and can utilize MIMO (Multiple Input Multiple Output) type of antenna.

1. Load capacity of the platform

The load capacity of the platform depends on the technology of the HAPS platform used, the energy supply, as well as the type of mission of operation and the environmental condition during its operation. Table 1 provides some information on the load capacity of the HAPS platform.

1. Safety and security of operation

The safety of operation of HAPS has to be in conformation with the safety standard of the national air transport authority, as well as with the ICAO. According to [30], the safety of HAPS operations is not strictly tied to individual vehicles. Rather, in order to function nominally, HAPS depend on functionality implemented as a set of interacting systems (vehicles, ground automation, command and control, airspace management, etc.). Anomalies and problems that arise are addressed by built-in automated processes, overseen by Fleet Reliability Engineers, Sub-system Specialists or a combination of them all. This autonomous implementation structure requires that the overall system be both vehicle and fleet sensitive.

Similarly for the security of the operation it also should comply to the national security regulation where HAPS is operated.

* 1. **The ground segments**

1. Gateway technology

The gateway technology of HAPS has similar function to the satellite gateway, which acts as interface to other network or to the Hub, as well as to connect to the HAPS payload, acts as backhaul. The gateway link uses any allocated spectrum to HAPS as indicated in the Table 2.

Gateway may also connect to HAPS indirectly via satellite link or by the inter HAPS link [32], in case the gateway location is outside the HAPS service coverage area or range.

1. Hub and user equipment technology

The Hub and user equipment technology of HAPS may be similar the one used in the satellite system. The data traffic from user equipment to the Hub is via the HAPS and Gateway.

1. Integration and connectivity to different networks

The integration and connectivity of HAPS system to other networks based on the similar concept and topology of satellite system where all interfacing are done via Gateway. In regard to the 7 OSI layers above layer-1 (physical layer) will be dealt by the users themselves, such as the IP routing dan data security.

1. Sites and power supply issues

In addition to the operation of HAPS as described in [21], would also consider the establishment of strong ground support for HAPS on aspects of maintenance, launching (take-off and landing) and gateway, where such site would have been carefully selected at location closed to essential supporting infrastructures, such as:

* continues power supply grid,
* highways or good roads,
* easy access for the helium gas supply (in case of Airship HAPS Platform),
* free from any conflict, earthquakes and any other potential natural disaster.

1. **The Applications and Use Cases**

The HAPS Alliance Reference Architecture (2025) outlines key use cases and applications for HAPS, including providing connectivity in underserved areas, filling gaps in cellular networks, supporting emergency response, and extending coverage over oceans [55]. Considering this paper, HAPS are identified as an integral component of multi-layered non-terrestrial networks (ML-NTNs), playing a critical role in enabling resilient and wide-area connectivity. Together with LEO and GEO satellites, HAPS form part of a unified architecture in which each layer contributes unique features depending on the use case. HAPS are particularly well suited for applications requiring low latency, high capacity, high penetration and flexible deployment—such as rural broadband expansion, white spot reduction, and emergency communications. In such contexts, coordination between HAPS and satellite platforms enhances overall network reach, adaptability, and robustness across land, sea, and air.

1. HAPS applications and uses cases concepts are also described in the document APT/AWG/REP-116 “Report on The Current Status and Future Plan on Regulations and Usage of HAPS in The Fixed Service in APT Countries” [21]. In this section the updates of HAPS applications and use cases regarding mobile broadband, earth observation and emergency communications/disaster recovery from the industry views are provided. Mobile Broadband

The Mobile Industry has as a primary objective to provide services to citizens and positively contribute to global digital inclusion. According to The Mobile Economy 2021 report from the GSMA, 8% of the global population did not have access to mobile services. However, there are geographical, social, cultural and economic conditions in different countries and regions that bring challenges that make traditional network deployment non-economically viable in some scenarios. Uncrewed High-Altitude Platform Systems (HAPS), which operate in the stratosphere, are the focus of increased interest in research and industry. HAPS could provide major benefits for the telecommunication industry and can complement terrestrial network operations by covering more surface area [22].

The 3GPP Release 17 has provided the opportunity to implement HAPS as part of the Non-Terrestrial Network (NTN) [23]. The NTN refers to networks providing connectivity through spaceborne vehicles (satellite), airborne platforms like airships and balloons, and UAS (unmanned aircraft system) platforms, which include UAVs (unmanned aerial vehicles) like drones. The 5G extends the possibilities of wireless communication, specifically opening up the door for unprecedented forms of machine-to-machine communications and applications like IoT and need to expand into non-traditional areas to ensure a degree of service continuity, where NTN comes into play. The following figure gives a general illustration of NTN platforms at different altitudes in space provide long-range coverage for a range of orders [24]. For the remote and rural area 3GPP developed the standard for NTN and for the urban area 3GPP developed the standard for UAV.

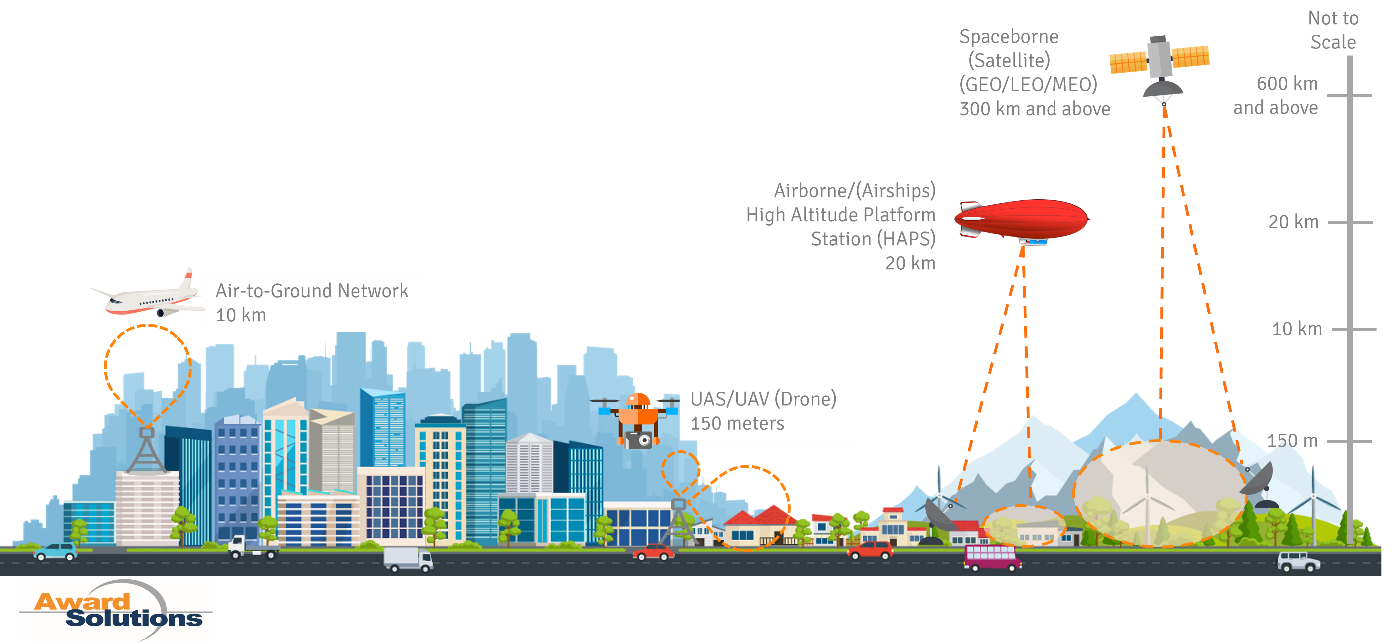


Figure . Different Types of Non-Terrestrial Networks.

1. Earth Observation

The use of HAPS platform can provide the earth observation services [25] [26]. The application is useful to support and assist such as:

* Forest fires and land protection,
* Maritime search and rescue, and
* Industrial emissions monitoring.

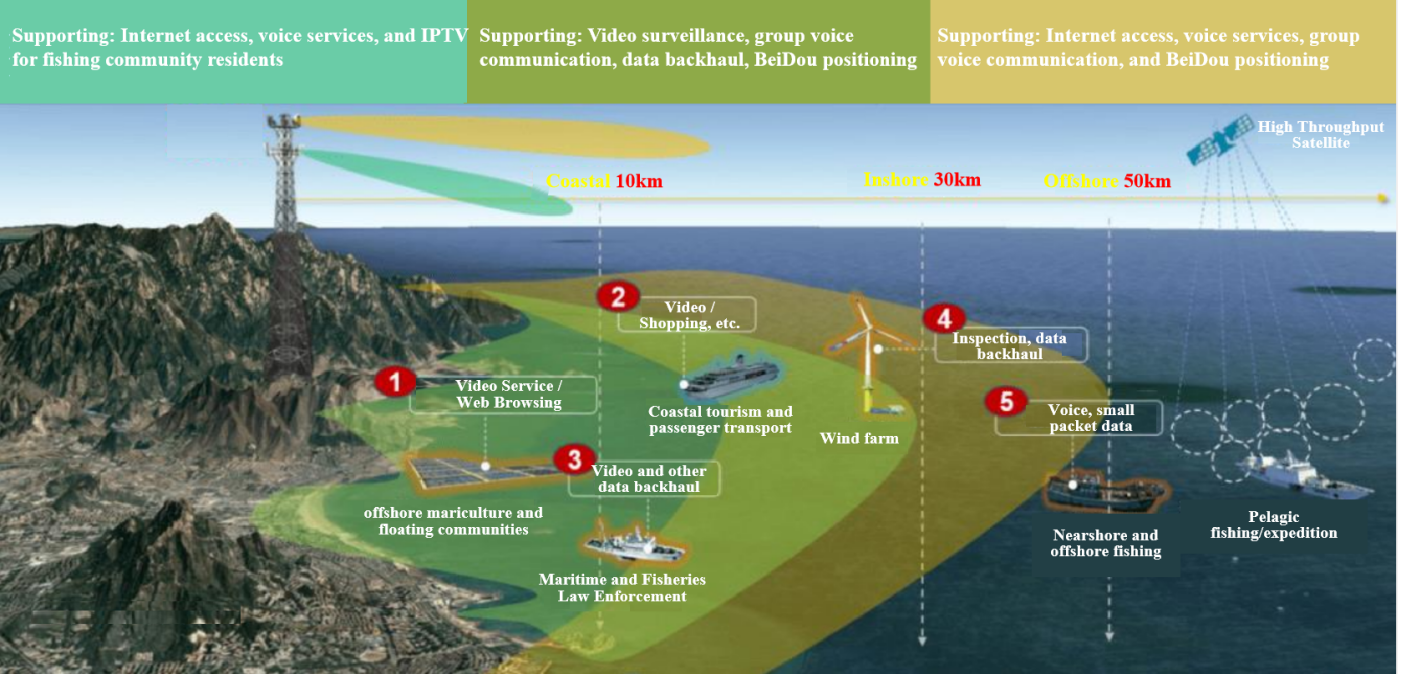
1. Emergency communications and disaster recovery

In recent years, mobile communication—available 24/7, 365 days a year—has become a vital part of social infrastructure, as people expect to stay connected anytime, anywhere. When mobile networks are disrupted during natural disasters such as earthquakes, tsunami and typhoons, it hinders rescue operations, survivor safety confirmations, and impacts daily life significantly. Therefore, it is crucial to rapidly deploy temporary mobile communication infrastructure in areas where connectivity has been lost due to such situations.

Using HAPS platforms equipped with mobile base stations to provide network coverage from above disaster sites is considered an effective method for providing mobile communication services during emergencies.

1. Application for ocean economy

High Altitude Platform Station (HAPS) demonstrates extensive application potential in the ocean economy due to its wide-area coverage, low-latency communication, and flexible deployment capabilities[55]. It can effectively compensate for the coverage limitations of traditional satellites and ground-based stations in offshore regions, addressing communication, monitoring, and rescue needs in the marine economy while promoting digital development in offshore regions, as shown in Fig. 6.



*Fig.6 HAPS supports the ocean economy*

* + - 1. Offshore Broadband Communication Coverage

HAPS can provide stable and low-latency 4G/5G network coverage for sea areas more than 50 kilometers offshore, solving the problem of communication dead zones for fishery, shipping and energy platforms, supporting real-time data transmission, safe communication and efficient operation scheduling.

* + - 1. Maritime Emergency Communication and Rescue

In accident sea area, HAPS can be quickly deployed as a temporary communication relay to ensure the transmission of distress signals and accurate localization, significantly improve the success rate of maritime search and rescue.

* + - 1. Marine Resources Exploration and Energy Development Support

HAPS is equipped with high-precision sensors, which can monitor the status of wind farms, offshore and seabed resources in real time, and transmit key data via large bandwidth links, reducing operation and maintenance costs and improving exploration efficiency.

1. **Demand requirements**

The demand requirements of HAPS are also described in [21]. In general HAPS is viewed as solution for remote and rural area. In the dawn of NTN, HAPS is perceived as a feasible element to provide 5G connectivity in remote and rural area.

1. **Case Study**
   1. **Demonstration experiment for emergency communications and disaster recovery**

HAPS is expected to serve as a rapidly deployable backup for mobile networks during natural disasters and to support emergency communications and disaster recovery efforts. In preparation for the commercialization of HAPS, a Japanese mobile network operator is advancing a project to build infrastructure using high-speed UAVs, whose technologies are expected to be applied to HAPS, as a countermeasure to quickly address disruptions to ground-based communication infrastructure during natural disasters in Japan. Conventional wireless relay systems using balloons or drones have limited coverage and require significant time to deploy. Therefore, a demonstration experiment was conducted using an aerial base station mounted on a UAV, which is capable of high-speed flight and covering much wider areas. [56]

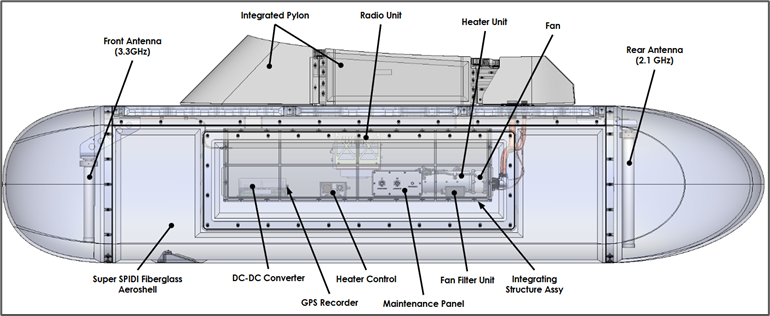


Figure 7 Pod with a base station.

High-speed UAVs combine high-speed flight with long-term endurance capabilities, enabling them to quickly reach disaster sites and operate wide-area base stations for extended periods. This allows for the provision of continuous network coverage at a disaster site and enables the rapid restoration and maintenance of communication infrastructure, even in areas that are difficult to access from the ground. By operating multiple platforms in rotation 24 hours a day, High-speed UAVs are expected to provide uninterrupted communication services and support activities such as situational awareness, evacuation guidance, delivery of relief supplies, and confirmation of survivors' safety.

Furthermore, high-speed UAVs’ large payload carrying capacity and power supply capability make it easy to expand communication capacity, allowing for the flexible and rapid enhancement of communication services according to disaster conditions and the needs of affected individuals. For example, depending on the situation at a disaster site, it is possible to increase network capacity and provide communication services to specific areas.

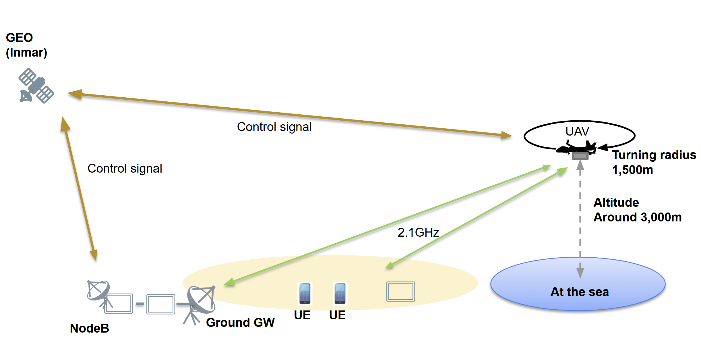


Figure 8 Framework of demonstration.

Figure 9 Demonstration experiment in the USA (Aug. 2024)

In a demonstration experiment, a custom designed aircraft-mounted case (POD) was developed to house antennas and existing wireless relay equipment (Duplex mode: FDD, service link used in the 2.1 GHz band). The POD was mounted on a UAV, and a flight test was conducted in the United States in August 2024. In this flight test, two sessions of four-hour flight experiments and radiocommunication tests were conducted. Radio signals were transmitted from ground-based stations in the direction of the UAV and received by the onboard wireless relay equipment. The received signals were then frequency-converted and retransmitted back to the ground. Radio propagation characteristics were measured for these communication signals.

As a result of the demonstration experiment, it was confirmed that there was no damage to the POD and payload, demonstrating sufficient durability, and that the environmental data inside the POD matched the results of theoretical calculations. Measurement and analysis of the signal propagation from the UAV demonstrated the feasibility of providing communication services to ground-based devices, such as smartphones, from the sky.

This initiative is expected to support lifesaving efforts and disaster recovery measures during emergencies.

Furthermore, the technologies and insights gained from this demonstration can also be applied to the commercialization of HAPS, demonstrating its potential as an effective means of providing continuous and stable network connectivity in regions where communication infrastructure has traditionally been insufficient.

* 1. **Commercial HAPS service in Japan**

A case study from a Japanese mobile network operator is the development of a commercial HAPS service [57], which leverages two types of platforms: HTA (Heavier-Than-Air) and LTA (Lighter-Than-Air) types. The company's strategic roadmap includes a phased approach, starting with plans to adopt LTA-type platforms in collaboration with its partner Sceye [26]. This choice is based on the platform's distinct advantages that are essential for providing a stable, persistent communication service.

These advantages include:

* High energy efficiency: Enabling extended, long-duration operational periods with minimal power consumption.
* Scalability for heavy payloads: The design allows for the easy expansion of volume and structure to accommodate a variety of high-weight communication equipment. For example, this platform can accommodate multiple payloads, including radio communication, sensing, and observation systems.

Phase 1. Pre-commercial service launch in 2026: This phase will initiate with limited area and time offerings, primarily for disaster preparedness scenarios.

Phase 2. Full commercial service launch after 2027: This phase will start for full-scale commercial services.

This phased approach is designed to create a concrete pathway to building a resilient and ubiquitous connectivity service that expands from disaster relief to include constant, everyday communication.

1. **Technology Roadmap**

Some of HAPS technology roadmap which could be briefly viewed are:

* Improving the Solar-Powered Platforms which significantly could reduces its carbon footprint compared to traditional aircraft and satellites. This reliance on renewable energy helps minimize greenhouse gas emissions [33][34].
* Energy-Efficient Designs through innovations in aerodynamics and materials that help reducing the energy consumption, which making long-duration flights more practical [33][34].
* Improving the Long-Duration Flights by relying more on solar panels to generate power during daylight hours, using advanced energy storage systems such as high-capacity batteries, using lightweight and durable materials to reduces the overall weight of the platform which in turn reduces the energy consumption, making better aerodynamic design to help minimize drag and improve energy efficiency, as well as applying the autonomous navigation and control systems, as the systems could optimize the flight paths and energy usage.
* Applying specialized antenna design to ensure effective communication over large areas, with some key aspects of antenna design:
  + Directional Antennas that will focus the signal in specific directions, which helps in improving the coverage and reducing interference which is crucial for both downlink and uplink communications [35].
  + Multi-layer Ring Cellular Structure which involves creating multiple layers of cells, where the beam width is adjusted to ensure uniform signal strength across different areas. The inner cells have wider beams, while the outer cells have narrower beams to balance the signal-to-noise ratio [36].
  + Form-factor and Size with aim to be lightweight and compact to fit on the HAPS platform. This is important for maintaining the platform’s stability and efficiency [37].
  + Steering and Mounting antennas to minimize the impact of wind and other environmental factors [37].
  + MIMO antennas is systems use multiple antennas to send and receive more than one data signal simultaneously. This increases the capacity of the communication channel. It also applies spatial multiplexing that allows different data streams to be transmitted simultaneously over the same frequency channel, effectively multiplying the data rate. Another advantage of MIMO, it can exploit the different paths that signals take to reach the receiver, improving signal reliability and reducing the likelihood of signal fading as well as can direct the signal towards the receiver more precisely, enhancing signal strength and reducing interference through beamforming technics.
* Improvement on HAPS payload capacity and efficiency through:
  + Multi-Mode Payloads that can switch between different operational modes to optimize energy consumption and extend loitering time. For example, a HAPS can operate in a super macro base station mode for enhanced computing and communication, a relay station mode for active communication, and a reconfigurable intelligent surface mode for passive communication [38].
  + High Throughput and Flexible Communication by integrating 5G and beyond technologies, such as massive MIMO and advanced antenna designs, has significantly increased the communication capabilities of HAPS. These improvements allow for higher data rates and more reliable connections over larger areas [39].
* Free-Space Optic (FSO) communication is a promising technology for inter-HAPS links (IHL) due to its high data rates and immunity to radio frequency interference, focus on:
  + Channel Modeling: FSO links between HAPS require precise channel modeling to account for atmospheric effects such as scintillation, turbulence, and pointing errors. These factors can significantly impact the performance of the optical link [40].
  + Adaptive ARQ Transmission for mitigating the effects of atmospheric disturbances, adaptive Automatic Repeat reQuest (ARQ) schemes can be employed. These schemes dynamically adjust the transmission parameters based on real-time channel conditions to improve reliability [40].
  + High Data Rates to achieve very high data rates, making them suitable for applications requiring large bandwidths. This is particularly beneficial for HAPS, which need to handle substantial amounts of data for communication and surveillance purposes [41].
  + Pointing and Acquisition to ensure the accurate pointing and acquisition of the optical beam where in an advanced tracking systems these are necessary to maintain alignment between HAPS, especially given their high altitude and potential movement [40].
  + Integration with RF Systems, where FSO links can be integrated with traditional RF systems to create hybrid communication networks. This integration can provide redundancy and enhance overall system reliability, especially in adverse weather conditions where FSO performance might degrade [41].
  + Relay Systems where HAPS can act as relay nodes in an FSO network, connecting ground stations or other aerial platforms. This relaying capability can extend the coverage area and improve the robustness of the communication network [42].
* HAPS propulsion technology developments are focused on:
  + Solar Power which are used by many HAPS to harvest energy during the day. This energy is stored in batteries to power the aircraft during the night. Solar power is favored for its sustainability and ability to support long-duration flights [43].
  + Hydrogen Fuel Cells where some HAPS use hydrogen fuel cells. These cells generate electricity through a chemical reaction between hydrogen and oxygen, providing a clean and efficient power source [43].
  + Hybrid Systems is the use of a combination of solar power and hydrogen fuel cells. This hybrid approach can provide a more reliable and continuous power supply, leveraging the strengths of both technologies [44].
  + Electric Propulsion system is powered by onboard batteries or fuel cells, to maintain the platform’s position and make minor adjustments. These systems are efficient and produce minimal noise and emissions [45].
  + Laser Ablation Propulsion involves directing a high-powered laser beam at a material surface on the HAPS. The laser energy vaporizes the material, creating a high-speed jet of plasma that propels the HAPS forward [46].

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