HAPPIEST

High Altitude Pseudo-satellites: Proposal of Initiatives to Enhance Satellite Telecommunications

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Introduction and objectives

The development of High Altitude Pseudo-Satellites (HAPS) has reached an outstanding level of maturity, with several flight demonstrations that augur soon to have operational capabilities. ESA, aware of the synergies among satellite and HAPS services, setup the HAPPIEST study to analyse the impact of the irruption of aerostatic HAPS into the telecommunications market, currently covered by space and terrestrial networks. Furthermore, some complementary payloads can serve interesting applications such as Earth observation and navigation services. The objective of HAPPIEST is

TO STUDY THE ROLE OF AEROSTATIC HAPS IN THE FUTURE TELECOMMUNICATION NETWORKS

identifying the most promising services and the resulting hybrid networks. In particular, a conceptual design has been developed in two reference scenarios where HAPS services are more valuable from the commercial point of view. This effort enables technical discussion on the technology maturity, economic estimations and programmatic solutions for a future ESA HAPS programme. The setup of a development roadmap for HAPS is another objective of the study.

Communication services

There are many communication services than can be offered by integrating HAPS into existing terrestrial or space networks. HAPS provide fast deployment capability, payload upgradability, simpler and/or smaller terminals and higher capacity links. Their geographical coverage is in between terrestrial and space based systems. After a comprehensive analysis of capabilities, the interesting services are: Direct To Home (DTH) Broadband, trunking, backhauling, High Throughput Services, tactical communications, mobile broadband and 5G. The provision of these services must be implemented in the bands allocated to HAPS by the current ITU regulation.

Complementary services

HAPS provide unprecedented persistent remote sensing with very high resolution. Besides, their long endurance enables the provision of long-term services similar to satellites. Although with limited coverage, HAPS also offer certain mobility and payload interchangeability. Thus, HAPS can complement and multiply the capabilities of current airborne and space based sensors. A trade-off analysis shows wide market niches in sectors such as security, maritime, emergency management, local planners and agriculture, with both private users and governmental bodies behind this interest. Besides, the availability of a HAPS platform opens opportunities for the provision of navigation services, either with stand-alone assets or with additional infrastructure to complement/augment existing infrastructure. GNSS signals also enable studies of water levels, biomass and atmosphere.

The services selected for further study present best operator or customer profits, wide demand, interoperability with currently existing systems and technical feasibility.

Reference Scenarios

Tactical scenario

In this scenario HAPS are used as a telecommunication back-up system upon natural or human-made emergencies or as an extension of existing networks to remote areas. For example, most of the migratory routes reaching Europe are maritime, with little coverage from terrestrial systems. Satellites are also useful in tactical scenarios but usually requiring specific terminals, which complicates the operational deployment. HAPS layer between ground and satellite provides interesting applications in devastated or remote areas, where this temporal solution is transparent for the end user. In this situation, special attention must be paid to possible interferences between HAPS and available ground stations, requiring proper coordination. When terminal modification is doable, new high bandwidth services can be developed (e.g. video streaming or 5G).

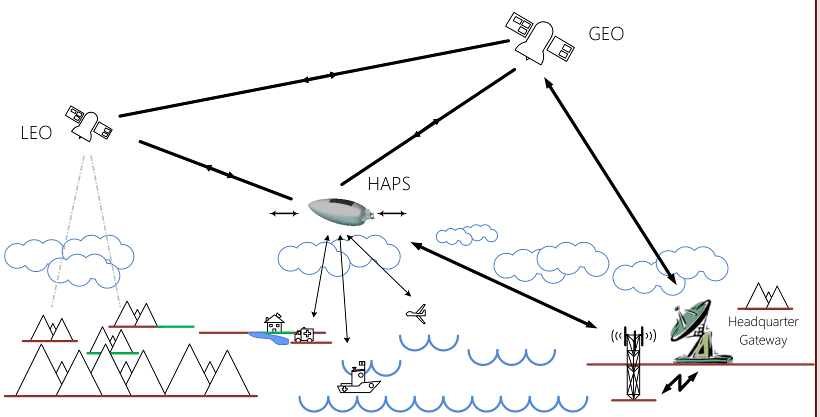


Figure 1: Scenario A - Tactical communications

The feasibility of TETRA and Broadband services over Lampedusa/Italy has been successfully proved.

Backhauling scenario

Among other options, HAPS present an undoubtable advantage to perform optical backhauling to space. In particular, HAPS can be used as a relay in the EDRS Space Data Highway. Bulky information from remote sensing satellites can be downlinked from GEO EDRS satellite through optical (or RF) links, free from atmospheric effects. The atmospheric path between HAPS and ground is short enough to simplify the link budgets in terms of power, antenna size or bandwidth. Additional features can be included in HAPS such as ultimate data processing, which can be upgraded more easily than in satellites. Moreover, provided that aerostatic HAPS are very stable and station-keeping is possible in many geographic locations, the scenario could include direct LEO-HAPS links to improve the current performance as GEO hops are not necessary.

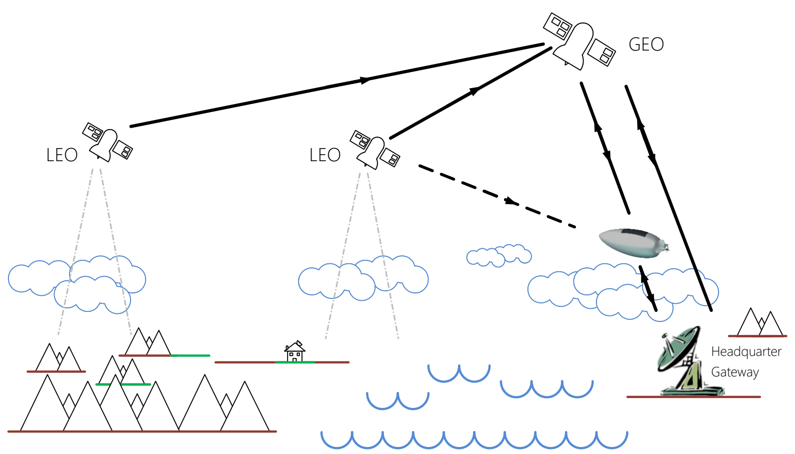


Figure 2: Scenario B - Backhauling communications

The feasibility of HAPS assisted EDRS services over Redu/Belgium has been successfully proved.

HAPS Performance

The size and complexity of HAPS platforms are dependent on the design airspeed, the altitude and the illumination hours. Key technologies are thin-film flexible solar cells (both efficiency and specific power), energy storage (batteries and regenerative fuel cells), large propellers, brushless motors and hull material. Current budgets are successful, and technology evolutions show even better margins in the near future.

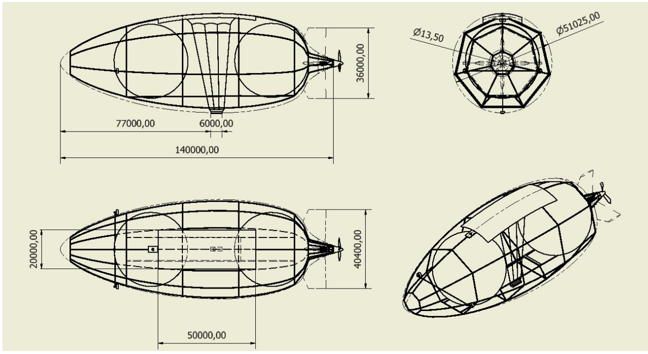


Figure 3: Preliminary HAPS drawings

Airships compensate the lack of density in stratosphere with extra buoyant volume, and this makes them always large. This complicates production and the ground operations. On its side, airplanes do that by reducing the wing loading, which makes them fragile and payload-mass limited. Thus, airships are much more scalable and with a huge potential to initiate a totally new market working together with satellites and terrestrial networks. Airships also provide longer lifetime and easier station-keeping in normal flights.

Communication services

Regarding the TETRA service, the frequency allocation proposed is 380/430 MHz (Rx/Tx), assuming 200 kHz dedicated with 25 KHz per carrier and TDMA access. The HAPS would serve 1280 users, broadening the coverage (~200 km radius) of current terrestrial network in a fully compatible fashion. The on board payload is estimated to be a 53 kg instrument with a power requirement of 190 W. In the case of the broadband connection service for tactical scenarios, the maximum throughputs depend on the region, reaching 1.2 Gbps in some sectors. The envisaged frequency plan includes 1900 MHz return channels and 2017 MHz (region 1&3) or 2140 MHz (region 2) forward channels. Payload mass is 260 kg with 1580 W consumption.

Backhauling scenario consists of a 1.8 GB, 1.55-µm optical link to satellite and a symmetrical 300 Mbps RF channel to ground (47.35 GHz downlink, 48.05 GHz uplink). Keeping the rest of parameters constant, the concept enables a reduction of ground antenna size from 6 to 2-m diameter. Payload 135 kg/370 W.

Complementary services

Detailed geometric and radiometric analysis has been developed to assess the HAPS Earth observation product quality. Geometrical distortions were evaluated using digital terrain models, with successful results up to 45 deg observation slat angles in most scenarios. The final setup consists of two multi-spectral instruments, one for continuous surveillance (25 kg/390 W) and the other with pan-tilt-zoom capabilities and extra fine resolution (33 kg/200 W). Cameras can be built from COTS elements with current TRL5/6 by adding specific protections against stratospheric chemical and thermal environments.

Finally, GNSS-R (reflectometry) and GNSS-RO (radio occultation) are foreseen (<5 kg/15W).

Development roadmap

The HAPS system is composed of various elements that are not always affected in the same manner by the test environment. The three major dimensions in the definition of the test environments are:

- The altitude of the test: apart from the operational altitude, tropospheric path is necessary for the ascend/descend phases

- The size of the vehicle: scale or shape-changed vehicles are useful to check materials, aerodynamics and control, software and other features of the final vehicle

- Duration of the tests: the natural cycle of 24 h is critical to observe continuous operations

Using ISO 16290 Standard notation, TRL4 and TRL5 of the different technologies can be obtained by testing the parts in the laboratory. Whereas TRL4 is normally achieved with conventional equipment, TRL5 requires the replication in the laboratory of a relevant environment (e.g. lab test chamber). Furthermore, TRL6 requires the parts to work together as elements or integrated systems in a relevant environment so, given the large size of the vehicle, this means prototype atmospheric flights. TRL7 also forces the stratospheric flight.

A roadmap is proposed to achieve an operational aerostatic HAPS for mixed services in telecommunication and Earth observation within a ten-year timeframe. To reduce technological and financial risks the roadmap follows a staggered approach as typically used in aerospace projects. The roadmap consists of four consecutive but overlapped phases (Figure 4). Within each phase design and develop activities take place in a coherent way to improve the technology of the relevant subsystems and the overall system en-block to a well-defined TRL.

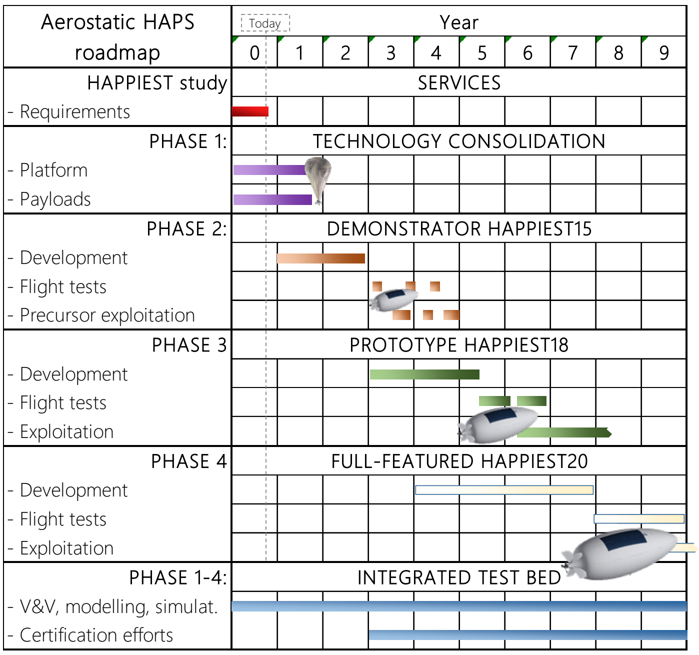
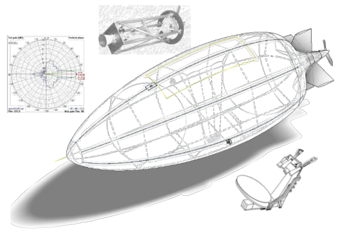
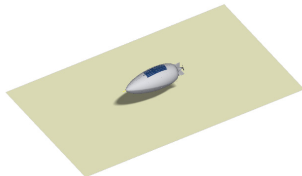
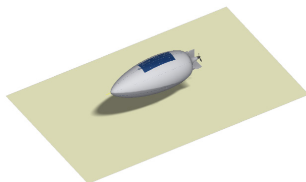
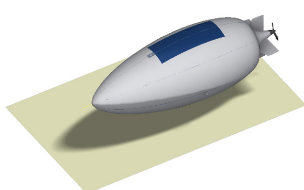


Figure 4: Proposed development schedule

In phase 1 the development progress is validated with an integrated test bed, in phases 2-4 with flight tests in the stratosphere using the integrated test bed as proof for achieved flight test readiness. In the roadmap it is planned to shift the system level TRL step by step from TRL5 (as provided by suppliers) to TRL8/9 (flight qualified system).

An integrated test bench will support phase 1-3 internal developments of the primary subsystems such as simulation and hardware-in-the-loop facilities for verification and validation.

Table 1: Main Summary of HAPS development roadmap

PHASE 1 HAPPIEST Technology Consolidation	Subsystems tested in relevant environment using test chambers; full payload performance tested in stratospheric balloons. Main concerns are hull fabrics, solar thin cell and battery efficiency, propellers and large electric motors. Flight control system must be extensively studied and simulated Target technology readiness level: TRL5 Phase duration: 1 year Platform type: subsystem breadboards 
PHASE 2 HAPPIEST15 Demonstrator	Engineering model, fully integrated, tested in relevant environment, reaching TRL6 Test of system performance, 7-day campaigns, power balance proof, subsystem efficiencies Development of operation procedures, transit, station keeping, controllability Payload/Service concept proof Target technology readiness level: TRL6 Phase duration: 2 years (development) + 2 years (tests) Platform type: 65-m airship, 25 kg payload, 15-km SL 
PHASE 3 HAPPIEST18 Prototype	Prototype tested in operational environment, looking for performance, reliability and product certification procedures, 200-day flight campaigns with many exploitation applications Verification of near full-scale design, including long endurance operation, flight mechanics, high-accurate station keeping. Payload/Service mostly operational Target technology readiness level: TRL7 Phase duration: 2 years (development) + 3 years (tests) Platform type: 100-m airship, 200 kg payload, 18-km SL 
PHASE 4 HAPPIEST20 Product & Services	Flight-qualified system providing full-featured products and services; more that 1-year continuous operation Test of system performance, reliability, and lifetime; tests of production machinery and ground infrastructure Payload/Service fully operational Target technology readiness level: TRL8/9 Phase duration: 4 years (development & certification) Platform type: 180-m airship, 250 kg payload, 20-km SL 

Conclusions

High altitude pseudo-satellites (HAPS) can offer many telecommunication services at regional scale. The most promising ones from the point of view of the economic and technical feasibility are:

- Tactical communications: back-up, temporal or precursor system to provide telecommunication services when natural disasters occur (e.g. earthquakes or floods) or when the scenario lacks from the required infrastructure (e.g. remote areas or deep sea) or when augmented performance is required (e.g. 5G). Digital radio and broadband services are among the proposed tactical communication services. HAPS can also be used as concept proof for new satellite services.

- Backhauling: the most valuable backhauling service among the ones studied is the use of HAPS as part of the EDRS Space Data Highway. The downlink from a satellite can be carried out in two steps: from the satellite to the HAPS and from the HAPS to ground. The first hop is prone to the use of optical links as it is free from atmospheric effects. The short path of the second, when compared to satellite height, improves the link budget enabling smaller antennae (cost saving) or wider bandwidth (revenue increase).

Worldwide frequencies allocated to HAPS are around 5 GHz (limited bandwidth available) and 47/48 GHz (high degradation and availability issues). Although feasible links have been demonstrated, the recommendation is to get frequency slots in Ku/Ka bands in order to provide better access to services.

- Complementary services: as a conclusion of a quantitative review of the Earth observation services, the ones showing larger gaps subject to be covered by HAPS are those related to security and defence, maritime applications, local planning, emergencies and agriculture. GNSS-based services can help with sea level monitoring and biomass estimations (signal reflectometry) as well as atmospheric research or meteorology (radio occultation).

In general, the HAPS payloads are evolutions from terrestrial, airborne or spaceborne operational instruments, including customised environmental protections and adaptations to required mission endurance. Besides, concept proof experiments can be developed from stratospheric balloon campaigns.

Despite their undoubtable value for commercial use, the stratospheric aerostatic platforms exhibit more immature technology levels. Although key technology is available in most of the subsystems (TRL4/5), there is no current evidence of operational capabilities of these systems as high as 20-km from sea level (TRL6). After a comprehensive analysis of representative environments for tests, a detailed development roadmap is proposed:

Following a staggered approach, models can be tested every 2 years, increasing from 15 to 20 km altitude, 25 to 250 kg payload mass and endurances from few days to a full year. This approach minimises the technical risk whereas enables a progressive development of the physical and regulatory infrastructures. First model can be flying in 2020 to have a full-featured product in 2025.