Antenna Implementations for High Altitude Platform Stations (HAPS) and considerations for future designs

Ogbonnaya Anicho, Philip B Charlesworth, Gurvinder S Baicher and Atulya Nagar
School of Mathematics, Computer Science and Engineering
Liverpool Hope University, Hope Park, Liverpool, L16 9JD, UK
Email: anichoo@hope.ac.uk

Abstract—This paper examines antenna implementations for the different communication links in a HAPS network i.e. service, inter-HAPS and feeder links. In this context, antenna implementation covers form-factor, size, steering and platform mounting templates. Antenna implementations vary significantly from one HAPS platform to another including proprietary and regulatory induced variations. Achieving the levels of link stability and performance demanded by current digital trends involves a steep technology and cost curve. This work proposes standardisation of HAPS antenna implementation to harmonise how antennas are implemented from design to installation. Accelerating the adoption of HAPS will require innovation at all levels of the HAPS technology value chain and antenna implementation is high up this chain.

I. Introduction

High Altitude Platform Stations (HAPS), which are stratospheric-based unmanned aerial systems (UAS) are expected to address communications infrastructure gaps in various segments of the global telecommunications landscape. For instance, rural connectivity gaps, backhauling solutions, traffic offloading are some of the implementation considerations for HAPS among others [1]. Advances in composite structures, solar and battery technology and the overall technological appetite for HAPS [2] is rising. The HAPS Alliance formed in February 2020 [3] has also contributed to increased awareness and synergies needed to accelerate the adoption of HAPS. HAPS come in different forms and can be deployed as heavier than air (HTA) platforms like fixed-wing aircraft or as balloons and airships which are lighter than air (LTA) platforms [1]. This paper, however, focuses on HAPS antenna implementations that are either in commercial trials or advanced technology readiness level (TRL); purely theoretical implementations are not considered. HAPS systems due to their unique operational environments present some challenges to antenna design and implementation. Unlike terrestrial systems, HAPS antennas will require specific considerations to function optimally. The mobility and attitude of the HAPS platform and the limitation of the antenna form factor constrained by size, weight and power (SWaP) considerations are significant. These attitude changes occur in all 6 degrees of freedom (6DOF). Translational and rotational motion can occur around all axes as well which can result in changes in polarisation as well as pointing. Antenna placement could be an issue with rotation around the vertical axis, particularly for inter-platform links where platform obstruction is a factor for consideration. In addition to antenna designs and implementation, considerations will also depend on the frequency of operation i.e. RF, microwave or mmWave bands and beyond.

The contribution of this paper is highlighting HAPS practical antenna implementation challenges and critical considerations for future antenna systems. Figure 1 shows HAPS communication links i.e. Inter-HAPS, service and feeder links where antennas are deployed for signal propagation. The Industry has made some advances to address some of the HAPS antenna implementation challenges especially for the service link segment of the network. In this paper, section I introduces the general concept of HAPS and HAPS antenna implementation. Sections II and III then goes on to discuss practical implementations of antennas in HAPS service, inter-HAPS and feeder links, establishing the state-of-the-art(SOTA). Section IV highlights considerations for future antenna designs and how to address antenna implementation challenges. Finally, section V concludes the work and considers future work.

II. Antenna Implementations for HAPS Service Links

To provide access to users on the ground the service link of any HAPS platform must be able to beam enough energy to meet service requirements (including the edge of the network). HAPS antenna systems deployed for the service link must meet SWaP requirements and all other regulatory constraints like antenna roll-off values and beam profiles. Unique platform characteristics must be considered as well, for instance, station-keeping and service manoeuvres which may involve consequential attitude adjustments. To overcome some of these challenges two antenna implementations from industry researchers provide some insights and are discussed in the sections below. However, the exact frequency or wavelength for which the antennas were designed could not be confirmed.

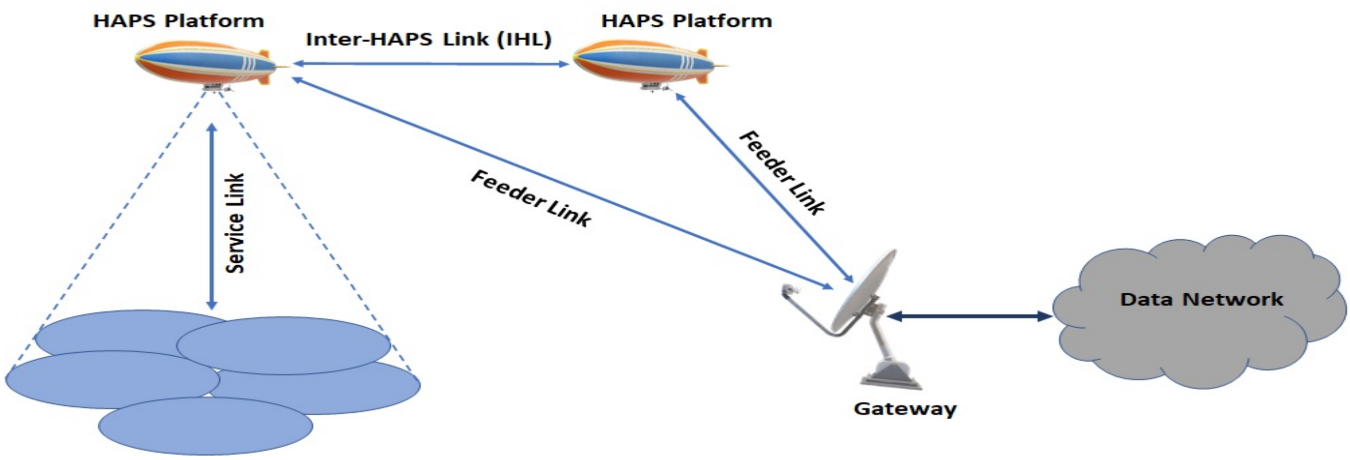

Fig. 1. Inter-HAPS & Service Link Diagram

A. Large Phased-Array Antenna

This HAPS antenna developed by Cambridge Consultants (CC) and Stratospheric Platform Limited (SPL) is considered the largest commercial airborne antenna [4] weighing about 120kg and over 3 metre square. It has an advanced phased array, 20KW power rating, creates 480 individual beams and 140 km even coverage of 5G signals. This antenna is designed to be large to provide high performance 5G coverage over vast geographical distances [4]. An advanced cooling technique ensures that the antenna system is adequately cooled. However, this antenna is adapted to fit SPL's hydrogen-powered unmanned aircraft weighing about 3.5 tonnes. This implies that the antenna in its current form cannot be easily fitted to other HAPS platforms. The engineering cost of adapting antennas to fit different platform designs and variants is a significant challenge. Much as this SPL antenna is considered novel, it does very little to address the wider consideration for a universally deployable HAPS antenna. The SPL documentation does not describe fully how the antenna compensates for platform attitude changes or other platform induced noise signals. It will be interesting to see how the antenna performs when fully deployed for service.

Fig. 2. Large HAPS phased-array antenna by CC & SPL [4]

B. Cylindrical multi-beam phased array antenna

The cylindrical multi-beam phased array antenna developed by researchers at HAPSMobile and Softbank fixes the footprint beamed from the fixed-wing aircraft [5]. This is achieved by using digital beamforming techniques to compensate for aircraft rotation by shifting the direction of the beams. The antenna can also be adjusted to respond to variations in service demands and population density or user distribution. Another piece of technology added to this antenna system is a rotating connector mounted between the communication antenna and the radio [5], which aids in fixing the footprint and stabilising the link. The exact weight and related technical parameters of this antenna are not publicly available. It will be helpful to understand how much the weight of the antenna contributes to the overall SWaP profile of the platform. The adaptation or modification needed to fit this to other HAPS is always a present challenge. However, the cylindrical antenna solves a major problem common in most fixed-wing HAPS antenna systems.

III. Antenna Implementations for IHL & Feeder Links

Inter-HAPS Links (IHL) connects two or more HAPS platforms, while the feeder link connects to a gateway, providing backhauling capabilities (see figure 1). The antenna implementation for IHLs can be quite challenging whether RF or optical-based. The antennas are required to achieve stringent pointing accuracies to maintain optimal link quality. This requirement can be challenging especially when platform induced noise signals are considered. The various forms of HAPS (fixed-wing, balloon or airship) will present different types of challenges/requirements to achieve optimal pointing ac-

Fig. 3. Cylindrical multi-beam phased-array antenna by Softbank & HAPSMobile [5]

curacies. The discontinued Loon Project (balloon HAPS) which was the first commercially deployed multi-HAPS network implemented these links by using parabolic reflector antennas [6]. These antennas were mounted on a controllable gimbal capable of rotating in both the Azimuth and Elevation directions to point to another HAPS balloon or downwards to a ground station (see figure 4). This enabled the Loon HAPS platforms to implement both service and inter-platform/feeder links from the same antenna assembly. Project Loon engineers

Fig. 4. Project Loon B2X Parabolic Reflector Antenna [6]

modified this antenna implementation for a fixed-wing platform in conjunction with HAPSMobile highlighting the challenge of adapting these antennas for a different platform. The performance of HAPS as a communication system will depend among other factors on the quality of the antenna designs and implementation.

IV. Considerations for Future Designs

To accelerate the adoption of HAPS, future antenna designs must not only focus on meeting technical and regulatory requirements but establish an antenna standardisation regime that addresses this 'implementation hitch". Standardising HAPS antenna assemblies and implementation will be quite challenging as the platforms come in different sizes and forms. The fixed-wing variant of HAPS requires significantly different considerations to the airship & balloon types. Antenna implementation for platforms with diverse engineering configurations will make standardisation a challenge. However, by harmonising designs across the industry, it is possible to minimise and mitigate this impact by reducing R&D cost or adaptation cost. For instance, a generic design for fixed-wing HAPS can standardise assembly and mounting templates, while individual HAPS platform vendors work out the platform to antenna weight ratio. This way each HAPS platform designer can design their HAPS platforms following an industry-wide antenna implementation framework with minimal proprietary content (assuming a harmonised frequency regime). Key players in the HAPS industry are beginning to collaborate at different levels (via the HAPS Alliance) but more coordinated and accelerated actions are required for issues like antenna implementation.

V. Conclusions and Future Work

Antenna implementations in HAPS systems differ significantly from one HAPS vendor to another. The difference also varies from one platform variant to another, with fixed-wing HAPS differing from both balloons and airships. Even within platforms of the same variant these antenna implementation differences exist exacerbated by proprietary consideration. Accelerating the adoption of HAPS may require the standardisation of antenna implementation to synergise technological efforts across vendors and leverage economies of scale. Future research direction will consider integrated payload designs, where payloads will implement antenna designs that can adapt to different use scenarios without any significant payload upgrade, thereby keeping costs low.

References

[1] GSMA. High Altitude Platform Systems: Towers in the Skies. Technical report, GSMA, 2021.

[2] HAPS Alliance. Driving the Potential of the Stratosphere. Technical report, HAPS Alliance, 2021.

[3] HAPS Alliance. Telecom, technology, and aviation industry leaders join forces to create the HAPS Alliance. https://hapsalliance.org/blog/, 2020. Accessed: 07-01-2022.

[4] Cambridge Consultants. The world's largest commercial airborne antenna: Beaming 5G from the stratosphere. https://www.cambridgeconsultants.com/case-studies/worlds-largest-commercial-airborne-antenna, 2020. Accessed: 07-01-2022.

[5] SoftBank and HAPSMobile. SoftBank Corp. and HAPSMobile accelerate High Altitude Platform Station (HAPS) R&D to provide stable and High-quality Connectivity for Future Commercial Services. https://www.hapsmobile.com/en/news/notice/2021/20210902_01/, 2021. Accessed: 07-01-2022.

[6] Project Loon Team. Loon Library: Lessons from Building Loon's Stratospheric Communications Service. Technical report, 2021.