HAPS Alliance

HIGH ALTITUDE PLATFORM STATION

HAPS Reference Architecture Series

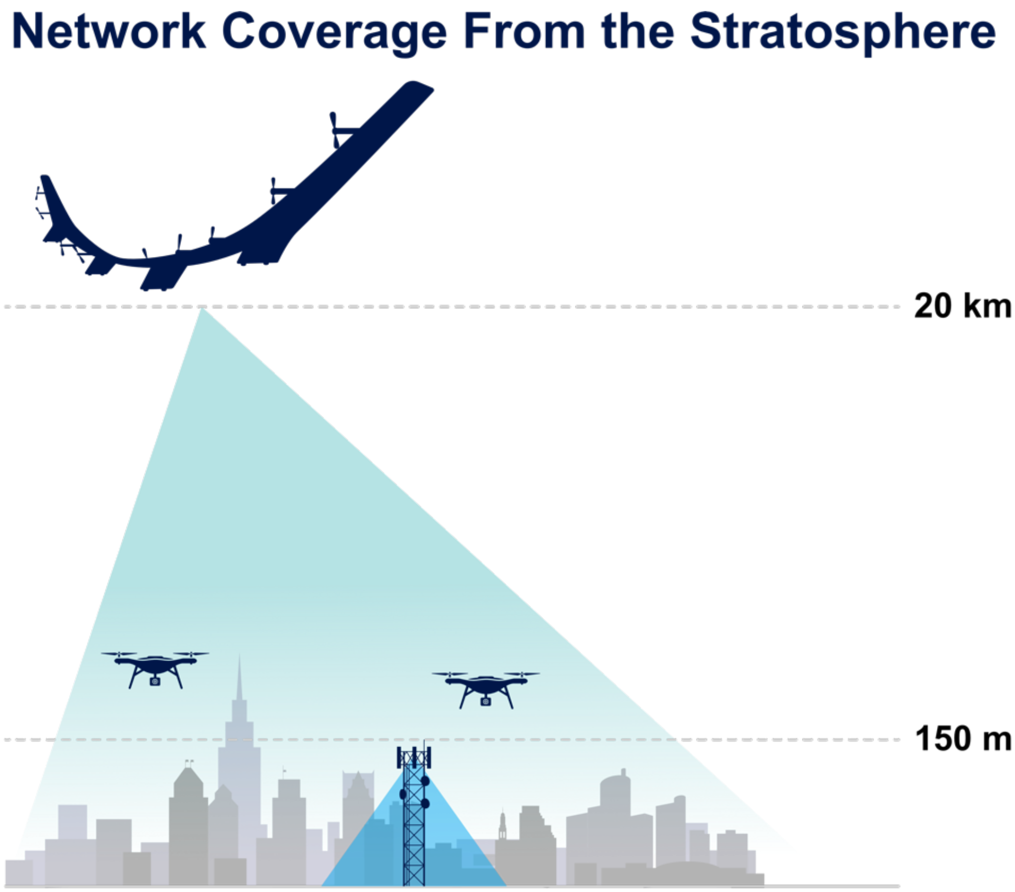
Cell Towers in the Sky

October 2024

Table of Contents

Introduction

Today, there are more than seven billion mobile phones being used around the world by people who rely on cellular service to facilitate their daily lifestyle. A large percentage of those users think of a mobile network as simply the device they can hold in their hands. For those that do understand that there is more “behind the curtain,” most of those people might think of the cell tower on the roadside but have little appreciation for the network complexity that lies out of sight.



High altitude platform station (HAPS) is a relatively nascent technology that promises to revolutionize the way mobile phone users connect to the internet. Over 2.7 billion people lack reliable internet connectivity. Once deployed at scale, HAPS networks will help to connect the unconnected by bringing internet service to remote and rural areas. When explaining “HAPS” to a new audience, we sometimes use an expression like “cell towers in the sky.” While this description can help to quickly paint a picture, it certainly lacks the fidelity needed to understand all that goes into a functioning HAPS network.

Formed in 2020, the HAPS Alliance is the leading voice in the industry—a consortium of over 80 member companies from the telecommunications, technology, aviation, and aerospace sectors, working together to unlock the stratosphere to enhance connectivity and sensing services for civilian and government applications globally. The business models of our membership range from service providers to platform builders, component manufacturers and more. Each of these members has joined the Alliance because they see a strong fit between their business and what is needed for HAPS to grow and succeed. The goal of this report, and others to follow, is to clearly describe all the pieces of a HAPS network and how those pieces interact with one another. In other words, to go beyond "cell towers in the sky." In so doing, we hope to enable current and future Alliance members to see where their products and services can fit in this new and revolutionary HAPS universe. This paper is the first in a series of reports aimed at this objective. In it, we will seek to answer these and other questions:

- *What services can be delivered through a HAPS network?*
- *What are the unique benefits associated with HAPS technology?*
- *What are the major constituent parts of a HAPS network solution?*

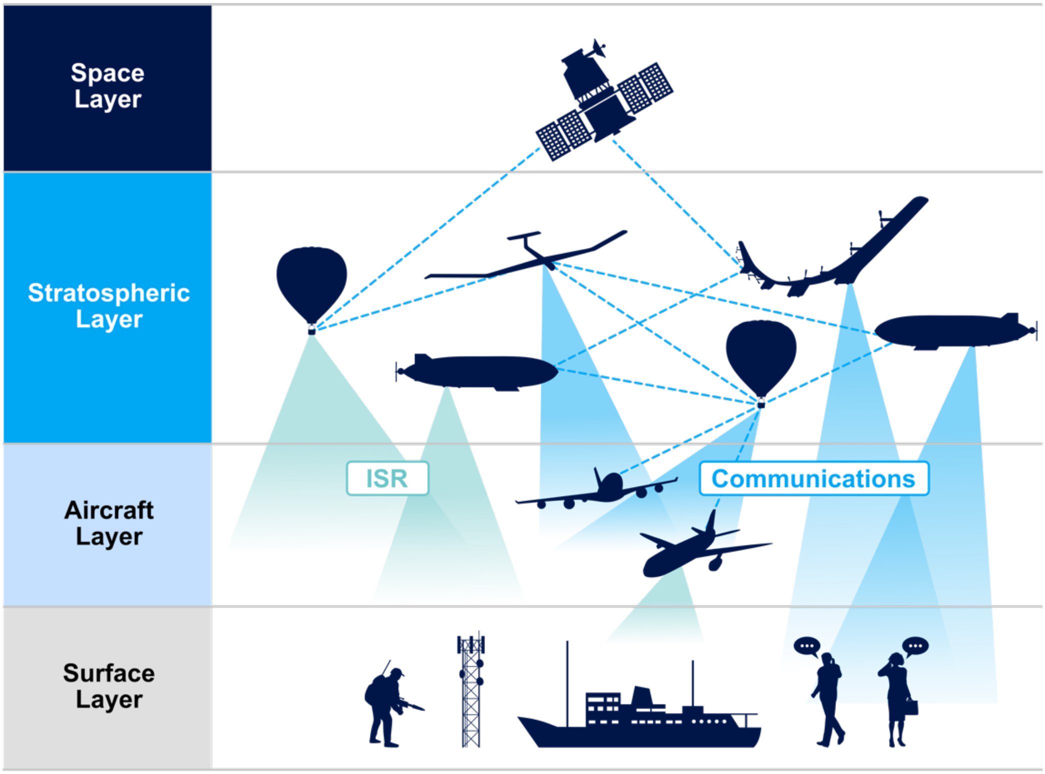
Based on the foundation laid in this initial report, future editions will more closely examine one or more of the major subsystems introduced in this publication. Additional content of future reports will include discussion of how architectures might vary as a function of the intended service offering as well as consideration of secondary subsystems and processes not introduced in this first edition.

What's in a Name?

The International Telecommunications Union (ITU) first coined the term high altitude platform station (HAPS) to mean "a station on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth." This range of altitudes is commonly referred to as the "stratosphere." Since the ITU's original definition, other interpretations of the "HAPS" acronym have emerged, each conveying a slightly different aspect of the technology. Two common examples include "high altitude pseudo-satellite" and "high altitude platform system." The former interpretation emphasizes the functional nature of HAPS being much like that of a satellite, albeit at much lower altitudes. The latter interpretation emphasizes the system complexity associated with the technology. Each of these interpretations serve a valuable purpose which will become more evident as this report continues.

HAPS Services

When first contemplated by the ITU, HAPS was envisioned as an alternative physical topology which could be used to augment traditional terrestrial network deployments, particularly in geographies characterized by challenging terrain and relatively sparse user populations. The choice of the very generic term “Station” was meant to afford flexibility in terms of which network function(s) were implemented in the stratosphere as opposed to the earth’s surface. In any event, the ITU clearly envisioned connectivity services as the primary use case for HAPS technology. Not surprisingly, most of the initial advancements in HAPS have come from the investments made by telecommunications companies, many of which are HAPS Alliance members. Notwithstanding this initial focus on connectivity services, HAPS technologies also support applications in other areas including earth observation, disaster management, maritime and defense. A more thorough exploration of HAPS services is publicly available on the HAPS Alliance website.



You will recognize that most, if not all, of these same service categories are also commonly discussed in the context of satellite networks, particularly low earth orbit (LEO). This fact underlies the “high altitude pseudo-satellite” moniker mentioned earlier. This brings us to the next discussion of the unique benefits associated with HAPS and how it can be positioned relative to terrestrial and space-based solutions.

Benefits of HAPS

The HAPS Alliance envisions a world where network connectivity is achieved through a heterogeneous network of land, sky, and space assets. Each of these layers has their own distinct value proposition. By combining elements of both terrestrial and satellite technologies, HAPS offers a unique combination of flexibility, scalability, rapid deployment and cost effectiveness. And unlike satellite technologies, HAPS networks can provide direct-to-handset performance that rivals traditional terrestrial networks in terms of speed, latency, and cost to the consumer. Analogous advantages relative to satellites apply for other service categories such as sensing and earth observation.

Understanding these advantages becomes straightforward when one considers the distances involved in land, sky, and space service links. Whereas the stratosphere may sound very distant, a 20 km link is not uncommon in many traditional terrestrial mobile networks. Add to this the very favorable propagation conditions associated with a link between earth and sky (absent the challenges of ground clutter) and the advantages of HAPS become apparent. Satellite solutions offer many of these same advantages but are fundamentally challenged by propagation distances which can range from 20x to 1000x that of HAPS links.

Framework for Discussion

Like other complex "system of systems," a HAPS network solution can be viewed/described either through a more physical lens or through a more functional lens. In the former approach, we can survey and account for each entity in the system (like a radio module). An alternative approach would be to describe the overall system as a collection of functional subsystems, each potentially spanning multiple entities, and where each entity may have a role in multiple subsystems.

Each approach has its usefulness. For example, we can examine the HAPS vehicle itself and describe all of its constituent parts including payloads. This approach would be quite useful when it comes to producing weight and power budgets. Alternatively, we can define functional HAPS subsystems such as the "feeder link." The feeder link will consist of both equipment on the ground as well as in the stratospheric HAPS vehicle. This approach will be most useful to understand functional interaction within and between subsystems. For the purposes of this first introduction to HAPS system architecture, information will be presented using a more functional sub-system approach.

A simplified schema for this initial examination is as follows:

Aviation systems

- Flight vehicle systems
  - *How do I stay aloft?*
- Energy systems
  - *How do I power the aircraft and its payloads?*
- Fleet orchestration, navigation and air traffic control systems
  - *How do I optimize fleet positioning and deconflict the airspace?*

Service systems

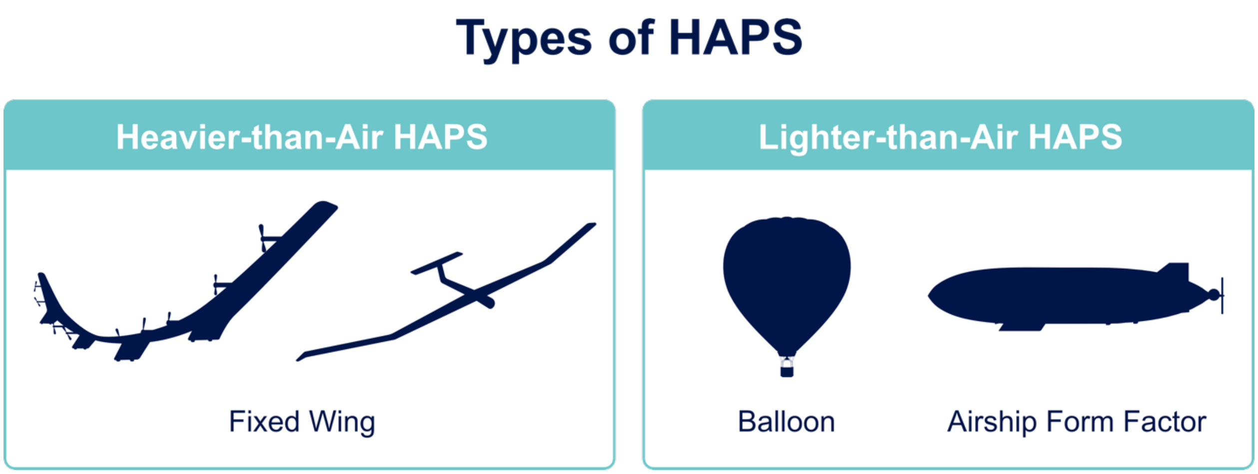
- Service link systems
  - *How do I connect ground-based users with the stratosphere?*
  - *How do I sense ground or airborne objects or particles from the stratosphere?*
- Feeder link systems
  - *How do I backhaul traffic to and from the stratosphere?*
- Core network systems
  - *How do I manage data and connect to the Internet?*
- Stratospheric network routing systems
  - *How do I effectively route traffic to and between multiple aircraft?*

Aviation Systems

Flight Vehicle Systems

It can be argued that gravity is a benefactor to both ground-based networks and satellite networks. In the former instance, gravity is responsible for keeping equipment held firmly in place. In the latter instance, gravity plays a fundamental role in orbital mechanics. For HAPS networks, on the other hand, gravity represents a challenge to overcome. Like aviation in general, stratospheric flight can be accomplished through various means.

In the HAPS industry, three classes of aircraft are emerging, each having certain advantages and challenges: fixed wing, balloon and airship. Like commercial aircraft, a fixed wing HAPS platform achieves lift through lateral velocity. These aircraft solutions offer superior maneuverability and station-keeping ability, but they must contend with the energy demands needed to maintain flight as well as payload weight limitations.



Balloons, on the other hand, are “lighter than air” platforms which are able to stay aloft by leveraging the buoyancy of lift gasses such as helium. This approach offers energy efficiency and significant payload capacity at the expense of maneuverability and station keeping. It should be noted, however, that modern stratospheric balloon technology can achieve significant navigation control through the exploitation of the varying wind patterns encountered at varying altitudes.

Finally, airships can be thought of as a hybrid of the other two platform types. They combine some of the advantages of lighter than air buoyancy with the navigation benefits of lateral propulsion. A detailed consideration of the relative merits of these three platform classes is outside the scope of this initial report but will be the subject of a future edition of this series. The HAPS Alliance believes that each platform class is completely viable, and that the optimal solution will depend not only on the specific intended service offering but also on cost, operational and regulatory factors.

Energy Systems

A discussion of HAPS can occasionally include use of a related term: high altitude long endurance (HALE). HAPS-based services will commonly require a significant degree of persistence, although not always. In an extreme example, a HAPS mobile network may be expected to provide 24/7/365 availability. These service requirements may or may not directly translate to duration requirements for each individual aircraft if some sort of fleet redundancy strategy is employed. Suffice it to say that regardless of the service offering and the fleet strategy, long endurance flight is a basic principle of HAPS.

By extension, energy systems that facilitate long endurance flight are a key consideration. With this in mind, the most common approach to the energy system is solar, with battery-based energy storage. Recent advancements in both solar and battery technologies, combined with new light-weight materials and energy efficient motors and payloads, have resulted in HAPS solutions capable of continuous uninterrupted operation.

Beyond the focus on solar power, other energy strategies are also being pursued in the HAPS industry. Traditional fuel-based engines as well as more innovative approaches such as fuel cells are being considered for HAPS solutions. Viability of these alternative energy strategies will commonly be coupled with alternative flight concept of operations (CONOPS). For example, instead of each HAPS aircraft staying aloft for several months, a CONOPS which is optimized for landing and refueling may be employed. These alternative strategies may be even more attractive in latitudes distant from the equator where collection of solar power is compromised in winter months.

Service offerings that do not require fully persistent HALE operation may open additional energy strategies. In all cases, the energy system must be sized to not only support flight but also to power all of the onboard systems and service payloads.

Fleet Orchestration, Navigation and Air Traffic Control Systems

Not unlike the previous discussion of the energy system, the requirements for this category can vary significantly as a function of the specific service or mission of the HAPS deployment. In general, services requiring a large number of HAPS flight vehicles over an extended time period will present more challenging requirements as compared to a single flight vehicle deployed for a time-bound mission.

By extension, as the HAPS industry continues to mature and stratospheric flight becomes increasingly commonplace, effectively deconflicting the airspace will become both more challenging and more essential. Proactively addressing these challenges is one of the primary goals of the HAPS Alliance in collaboration with agencies such as the U.S. Federal Aviation Administration (FAA).

The HAPS Alliance envisions a collaborative traffic management for the stratosphere (CTMS) operational end-state that enables safe and scalable operations of HAPS operating at altitude as attended autonomous fleet systems. White papers outlining this vision are publicly available on the HAPS Alliance website.

Of course, operating safely is only one part of this requirement category. Deploying a fleet of HAPS aircraft in a way that satisfies the service requirements is equally important. Once again, the exact service requirements will drive the system architecture. As a general rule, the fleet orchestration system will be composed of ground-based compute resources, coupled with on-board logic in each HAPS flight vehicle. Command/control and telemetry data links will connect ground-based and airborne systems. These data links may include levels of redundancy to ensure adequate reliability.

For example, the feeder link (discussed later in this report) may be utilized as a primary link with satellite communications employed as a backup system. Collectively, these systems will continuously analyze fleet positioning as it relates to the service topology on the earth below, weather conditions, and other factors, and make navigation commands accordingly.

Service Systems

Service Link Systems

The term “service link” is most commonly used in reference to connectivity services such as direct to handset cellular service, although other services, such as imaging, can be supported by HAPS and will involve a very different sort of service link. For the purposes of this introduction to the service link, a 3GPP-based connectivity service will be assumed. Other service types will be considered in future editions of this series. Architecting a HAPS-based 3GPP service link involves consideration of a very large number of factors, including the following:

- Target coverage area
- Target service quality level (availability, throughput, etc.)
- Fleet strategy
- Spectrum strategy
- Fight vehicle mass and power constraints
- Feeder Link capability

A more in-depth consideration of these and other factors will be the subject of a future edition in this series. For purposes of this introductory discussion, the following summary is provided.

For those who have studied 3GPP radio access network (RAN) architectures, the notion of a “split architecture” will be a familiar concept. The idea is to co-locate some, but not necessarily all, of the base station functionality at the tower/antenna site. Different functional splits can facilitate different demands placed on the various network elements, cost, and overall performance.

This same trade-space is applicable to base stations for a HAPS service link: What functions are implemented in the HAPS payload, and which remain on the ground below?

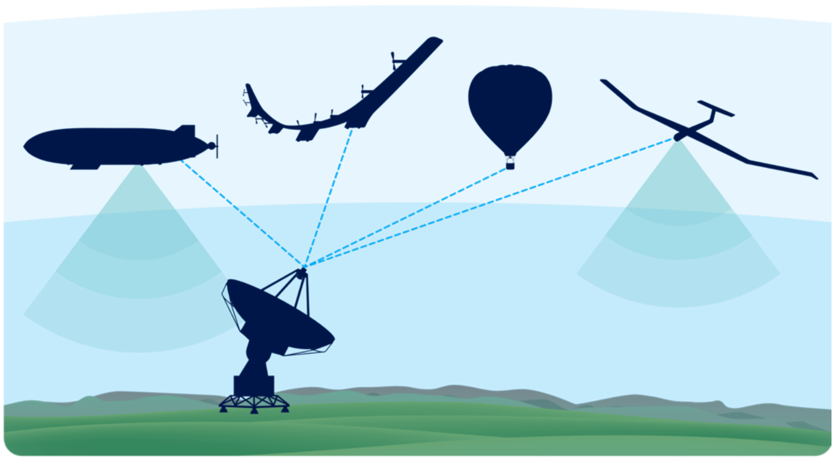
Evaluation of this trade-space is complex. Suffice it to say that at a minimum, the HAPS service link payload will include radio frequency (RF) transmitter and receiver hardware and the base station antenna solution.

Where baseband processing is located, for example, will be a function of the chosen architecture. Much like a traditional terrestrial base station, these RF elements will significantly define the coverage pattern provided by the HAPS base station. The patterns can range from relatively simple omnidirectional patterns to more complex sectorized patterns. Solutions involving beamforming may be employed which can allow for more targeted concentration of the base stations' capacity. Similarly, antenna solutions which seek to minimize the apparent movement of the coverage regions (as the HAPS vehicle moves) have been considered. Regardless of the chosen implementation, HAPS coverage areas are typically orders of magnitude larger as compared to terrestrial networks. Such solutions are well suited for remote and rural geographies having relatively sparce user densities. Finally, to complete the Service Link, 3GPP-compliant user terminal equipment on the ground is assumed.

Non-communications service link components (for example imaging or Earth observation sensors) have many of the same considerations. Whether processing remains onboard the flight vehicle or on the ground, how vehicle power can support different elements of the system, how directional elements are incorporated (such as gimballed or electronically steered elements), and the data requirements for the feeder link are all common trade-space areas for many types of service links.

Feeder Link Systems

As the name implies, the feeder link's task is to feed the stratospheric HAPS vehicles with the data needed to facilitate the intended service, as well as collect data in the reverse direction. The familiar term "backhaul" is generally synonymous. Feeder links may include RF or free space optics links, and these links may be made between the ground and the HAPS vehicle, to a satellite layer or inter-HAPS.



One common feeder link architecture involves one or more ground stations having antenna solutions aimed skyward. The HAPS payloads will include corresponding radio/antenna solutions designed to establish radio links with the ground stations below.

Much like backhaul links used in a traditional terrestrial network, the HAPS feeder link will carry both user data and control data. In the case of a 3GPP-based HAPS solution, the feeder link will carry the user plane and control plane data which correspond to the chosen architectural split as discussed previously. For example, if a 4G LTE base station (eNodeB) is fully implemented in the HAPS flight vehicle, then the feeder link would carry the S1 interface between the base station and the core network. In addition to the standardized 3GPP control plane data, the feeder link will also carry command/control and telemetry data based on aviation requirements for the HAPS flight vehicle.

It should be noted that, in a HAPS system architecture, there is an extreme case of an architectural split where all of the base station signal processing is implemented on the ground. In this case, the feeder link essentially becomes a transponder or RF relay. This architecture is commonly referred to as a “transparent” or “bent pipe” architecture. Conversely, architectures which involve some/all of the base station functionality being implemented in the HAPS payload are commonly referred to as a “regenerative” architectures. The relative advantages of transparent vs regenerative architectures will be the subject of a future edition of this series.

One very important consideration of the feeder link architecture is the possible inclusion of HAPS-to-HAPS links. In deployments involving a fleet of multiple HAPS flight vehicles, the system design could simply employ one dedicated ground-to-HAPS link for each vehicle. Conversely, the feeder links intended for multiple vehicles could be multiplexed together. Connectivity would then be established from the ground to only one vehicle in the stratospheric constellation. Inter-HAPS links would then redistribute the data accordingly. Once again, there are a great number of factors to be considered in arriving at the best system architecture. Further, the decision to employ inter-HAPS links should be made in concert with a decision regarding regenerative vs. transparent architectures. Finally, the decisions regarding what frequency bands to use for the feeder link (and inter-HAPS links) must also be contemplated in the overall architectural choice. Different bands will offer different trade-offs between bandwidth, propagation characteristics, cost, and performance.

Core Network Systems

The term “core network” can take on a wide range of meanings depending on the type of services offered by the HAPS system and the scale of the system. In telecommunications, the core network typically refers to a set of functions spanning:

- Subscriber management, authentication, and charging
- Routing of data both within the network, and in/out of the network
- Data session management

For 3GPP-based networks, the core network functions and interfaces between functions have been standardized. In general, implementation of a HAPS-based 3GPP network will require little to no deviation from those standards. Some complexities can be introduced depending on if/how the HAPS network is meant to be integrated with a terrestrial network, and which parties are responsible for the management of the respective networks and users of those networks.

A range of possibilities exist. One simple example would be a stand-alone HAPS network meant to provide direct-to-handset service to a population of end-users. In this case, the HAPS network would need to include a full functioning stand-alone core network. Other scenarios might include arrangements where the operator of the HAPS network could offer wholesale connectivity to one or more terrestrial mobile network operators (MNOs). In such a scenario, there might be two (or more) core networks interconnected via standards-compliant interfaces. One of those core networks would be controlled by the HAPS network operator and would focus on the data session management. The second might be operated by an MNO and would focus on subscriber management aspects. Core network functionality for a HAPS network will most commonly be implemented in ground-based equipment. That equipment might be located very near the intended service area, or potentially very distant, as a function of latency, cost, and regulatory requirements.

Stratospheric Network Routing Systems

Software defined networking (SDN) is a well-established architectural approach to data routing and network optimization in multi-node data networks. As such, these basic principles are likely to be incorporated in a HAPS system composed of multiple HAPS vehicles and multiple ground stations, serving a time/position varying user population. What can make the SDN solution for HAPS significantly more challenging are certain factors not commonly encountered in more traditional terrestrial networks.

In a HAPS network, the network nodes themselves are both moving and potentially moveable in a controlled manner. This presents both a challenge and an opportunity for real-time network optimization. This will be particularly true when, in addition to time-varying service links and time-varying feeder links, the HAPS network also includes time-varying inter-HAPS links. Compounding the time/space variability of these links, and the traffic demands on the earth below, can be the somewhat unpredictable weather and radio propagation conditions which can affect these channels. Collectively, these complex variables can translate to the need for a highly sophisticated solution. This solution will commonly be a software-based solution running on ground-based compute resources.

Given the logical coupling between this system and the fleet navigation systems, there will commonly be interfaces between the two.

Conclusion

On some perfectly clear summer day, we might gaze up into the afternoon sky and see a tiny glimmer of sunlight reflecting off a HAPS vehicle: a "cell tower in the sky" helping to bring ubiquitous connectivity to those below. For you, we hope that this tiny glimmer serves as a reminder of the complex system of systems that compose a HAPS network, all working harmoniously to accomplish the intended goals.

In this first of what will become a continuing series of reports, we have examined the HAPS system from a very broad and cursory vantage point. Our aim is to enable current and future Alliance members to see where their products and services fit in this new and revolutionary HAPS universe, by exploring these and other questions:

- What services can be delivered from a HAPS network?
- What are the unique benefits associated with HAPS technology?
- What are the major constituent parts of a HAPS network solution?

Based on the foundation laid in this initial report, future editions will more closely examine one or more of the major subsystems introduced in this first publication. Additional content of future reports will include discussion of how architectures might vary as a function of the intended service offering as well as consideration of secondary subsystems and processes not introduced in this first edition.