High Altitude Platform Station based Super Macro Base Station (HAPS-SMBS) Constellations

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Abstract—High altitude platform station (HAPS) systems have recently attracted renewed attention. While terrestrial and satellite technologies are well-established for providing connectivity services, they face certain shortcomings and challenges, which could be addressed by complementing them with HAPS systems. In this paper, we envision a HAPS as a super macro base station, which we refer to as HAPS-SMBS, to provide connectivity in a plethora of applications. Unlike a conventional HAPS, which targets remote areas or disaster recovery, we envision next-generation HAPS-SMBS to have the necessary capabilities to address the high capacity, broad coverage, low latency, and computing requirements especially for highly populated metropolitan areas. This article focuses mainly on the potential opportunities, target use cases, and challenges that we expect to be associated with the design and implementation of the HAPS-SMBS based future wireless access architecture.

INTRODUCTION

It is widely acknowledged that flexible and agile solutions for wireless connectivity will play a key role in future wireless communication systems. Currently, the connectivity requirements in terrestrial networks are addressed mainly by the densification of network infrastructures [1]. However, densification solutions do not appear to be sufficient to address the ever-increasing user demands which are getting more and more unpredictable in space and time. In other words, no matter how dense most parts of the network is (with small base stations (BSs) in addition to macro BSs), a demanding application (such as immersed reality) can temporarily arise at a locality in which the network infrastructure may be relatively sparse. In light of this, the seamless integration of terrestrial and aerial networks, known as vertical heterogeneous networks (VHetNets), has emerged as a promising architecture [2].

In the current state-of-the-art, the emergence of low earth orbit (LEO) satellite constellations have been identified as a promising solution for enhancing network coverage [3]. However, we note that LEO constellations have two major shortcomings: a) direct LEO to user equipment (UE) connection is difficult with the current technology due to high path loss, and b) frequent handoffs will be encountered due to the high mobility of LEO nodes. Hence, a potential complementary solution to the wireless capacity and coverage enhancement lies in aerial platforms. The utilization of aerial platforms for 5G wireless communication systems have already been considered in 3GPP Release 17 [4].

The envisioned aerial network is composed of two interacting sub-layers which offer agile network functionalities. The first sub-layer includes moving unmanned aerial vehicle (UAV) nodes, whereas the second sub-layer is composed of high altitude platform station (HAPS) systems, which are the quasi-stationary network elements. The International Telecommunication Union (ITU) has defined a HAPS in Article 1.66A as “A station on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth”. Most current deployment plans target an altitude range of 18 to 21 km. We believe that this HAPS sub-layer will provide important functions both in terms of capacity and coverage improvements by enabling the best features of both terrestrial and satellite communications. Motivated by these advantages, this paper discusses the significant role that HAPS systems can play in the future wireless access networks.

HAPS research dates back to the late 1990s [5]. Despite many advantages that HAPS deployment promised, their implementation was very limited at that time. In recent years, there has been a substantial increase in research efforts and commercial application plans for different HAPS technologies [6]. These developments have made HAPS systems more viable network element thanks also to the evolution of communication networks and advances in solar panel efficiency, battery energy density, lightweight composite materials, autonomous avionics, and antennas. With these advancements, in practice, the potential applications of a HAPS can be substantially
TABLE I: Summary of the features of a HAPS compared to a UAV and a VLEO & LEO satellite

| Parameters                  | UAV          | HAPS         | VLEO         | LEO          |
|-----------------------------|--------------|--------------|--------------|--------------|
| Operational altitude        | 100 – 400 m  | 20 – 50 km   | 250 – 500 km | 400 – 2000 km|
| Cost                        | Low          | Medium       | Medium       | High         |
| Round-trip propagation delay| 0.66 – 2.66 µs| 0.13 – 0.33 ms| 1.66 – 3.33 ms| 2.66 – 13.33 ms|
| Communication endurance     | Short        | Long         | Long         | Long         |
| Resource limitation         | High         | Low (empowered by solar battery charging) | High | High         |
| Mobility                    | Varying speeds| Quasi-stationary | Fast | Fast         |
| Coverage area               | Small        | Wider        | Wider        | Wider        |
| Path loss                   | Low          | Low          | Medium       | High         |

broader than the conventional scenarios targeting remote and disaster applications.

In this article, we envision HAPS as a super macro BS, which we refer to as HAPS-SMBS, to cover a large metropolitan area in line with the smart city paradigm. The urgency of increasing traffic volume in complex urban scenarios as well as the problems of deploying terrestrial BSs and LEOs motivate us to consider the deployment of HAPS-SMBS. For example, in order to provide coverage for such a metropolitan area, a large number of ground BSs, as well as a backhaul network, may be needed. This high cost of infrastructure would be a major concern compared to a HAPS-SMBS. By contrast, a HAPS-SMBS is an excellent interface to mask both high path loss and the high mobility effects of LEO constellations. To solve the first problem, the UE can connect to a HAPS-SMBS with radio and a HAPS-SMBS to an LEO with free space optics (FSO). Since HAPS are almost geostationary, there are no mobility management related problems. The envisioned HAPS-SMBS can provide wireless services and assist the terrestrial network with the provision of distinct features, such as data acquisition, computing, caching, and processing. Fig. 1 summarizes the promises and novel target use cases of a HAPS-SMBS as a main component of wireless access architecture. This is detailed in the subsequent sections.

AERIAL NETWORKS

Nowadays, aerial networks have received growing interest for their potential to improve network design both in terms of capacity and coverage. Aerial networks consist of two network components: HAPS and UAV nodes.

High Altitude Platform Station (HAPS) Systems

HAPS was a popular research topic in the late 1990s and early 2000s with many distinct areas of investigation [5]. However, all these earlier visions as well as the current Google Loon project aim to bring remote parts of the globe online and for disaster applications. In contrast, we envision a HAPS-SMBS as another type of BS in a multi-tier VHetNet architecture to be deployed particularly in dense urban areas. Table I summarizes the features of a HAPS compared to a UAV and a very low earth orbit (VLEO) & LEO satellite.

Unmanned Aerial Vehicles (UAVs)

Unlike HAPS with their quasi-stationary positions, UAVs are networking elements with relatively high mobility. The UAVs can be of two functions:

UAV Base Stations: The coverage and capacity improvements offered through the use of UAV mounted aerial BSs is a well-studied topic in the literature [7], [8]. This concept is being actively investigated by 3GPP [4]. The 5G system should be able to support UxNB (the 3GPP term for a UAV-BS) to provide enhanced and more flexible radio coverage.

UAV as User Equipment: The use of UAVs as UE, such as drones is already supported through existing terrestrial networks. In particular, the use of UAVs as UE is currently being promoted by mega-retailers who would like to use the drones to carry courier packages.

To this end, an overview of how to make use of UAVs in wireless networks is provided. In the following sections, we investigate the latent opportunities and challenges of HAPS in future wireless access networks.

HAPS ADVANTAGES

The promise of HAPS as a main component of wireless network architecture can be listed as follows.

Favorable channel conditions: HAPS are expected to be only 20 km away with line-of-sight (LoS) links. This distance, combined with the high probability of LoS channels provides a relatively low channel attenuation. Hence, a direct link with ground UE is possible. At a low altitude, when compared to LEO satellites located 400 km to 2000 km away, this provides a much more favorable link budget. In terms of downlink, the corresponding favorable channel conditions provide a high signal-to-noise ratio (SNR) for the downlink and a coverage advantage, including for highly populated areas.

(Almost) Geostationary positions: The position of a HAPS is relatively stationary. This means capacity is not wasted by orbiting over unpopulated areas (e.g., oceans), at all times connectivity from the same location can be enabled. The stationary status of a HAPS avoids the introduction of a significant Doppler shift. Furthermore, no tracking of the devices are needed. The stationarity of a HAPS also provides a basis for a main mobility management node, which can contribute towards the handoff management.

Smaller footprint compared to satellite nodes: The smaller footprint due to lower altitudes, when compared to satellite nodes, provides a higher area throughput, and improved resource utilization capability.

Large platform: A HAPS can be larger than a big building, and according to the recommendations of the ITU standard, its position should be maintained in a cylinder with a radius of 400 m and height of ±700 m [9]. Hence it is suitable for multiple input multiple output (MIMO) and massive-MIMO
significant developments in aeronautics, wingspan, and other
coverage is potentially feasible in the near future. Additionally,
using a 35 m wingspan HAPS platform is approximately 80
kWh. Hence, a solar power based HAPS-SMBS with extended
energy required for 24 hours of continuous HAPS mounted
for a service area radius of 60 km. It was shown that the total
and how much solar energy can be harvested. For example,
using a HAPS to cover even a temporary hot spot at the ground
is possible. In addition, due to the large size of a HAPS, it
can be equipped with wide solar panels and energy storage
systems to sustain it with the energy it requires.

Even lower latency: The relatively low altitude of a HAPS
also provide a 40 km to 100 km round-trip distance, which
corresponds to a round-trip delay of 0.13 ms to 0.33 ms.
Hence, HAPS based connectivity does not suffer from the
high-latency problems of satellite networks, which makes a
HAPS suitable for low-latency applications.

Hybrid connectivity: ITU has already dedicated 600 MHz
of spectrum for HAPS [10]. In addition to the dedicated band
and terrestrial cellular bands, FSO is a promising alternative
for providing multi-connectivity to robust and/or high data rate
communication systems. One leading solution is to generalize
the multi-band radio frequency (RF) links with hybrid RF-
FSO connections. This approach will trigger a change of the
classical radio access architecture to a more generalized
wireless access architecture paradigm.

HAPS Super Macro Base Stations

A macro BS is a fundamental element in any HetNet wire-
less infrastructure for providing coverage and support capacity.
Due to the inherent characteristics of quasi-stationarity, the
larger footprint compared to UAVs, and the LoS channels,
the envisioned HAPS mounted super macro BS can serve as a
powerful platform to enhance coverage and capacity, as shown
in Fig. 2. HAPS-SMBS improve the flexibility of the network
design. The presence of HAPS-SMBS reduces the need for
communication network over-engineering, which is done to
match the requirements of peak demands. Therefore, the
terrestrial network can be designed to satisfy the average user
requirements, and the rapidly changing (and often unpredictable)
high demands can be simply addressed through a HAPS-
SMBS. It should be emphasized that we refer to this BS as a
super macro BS because of its large coverage area with M-
MIMO and the provision of supporting distinct features, such
as data acquisition, computing, caching, and processing.

However, with increasing the interest in HAPS-SMBS, it is
imperative to access the feasibility of its deployment mainly
considering the energy consumption constraint. In this vein,
there has been a successful deployment of aircraft-based solar-
powered HAPS [11]. Energy management of HAPS-SMBS re-
quires the investigation of how much energy will be consumed
and how much solar energy can be harvested. For example,
the authors in [6] estimated a HAPS BS power consumption
for a service area radius of 60 km. It was shown that the total
energy required for 24 hours of continuous HAPS mounted
macro BS operation at full capacity was approximately 70
kWh. By contrast, the available solar energy provisioning
using a 35 m wingspan HAPS platform is approximately 80
kWh. Hence, a solar power based HAPS-SMBS with extended
coverage is potentially feasible in the near future. Additionally,
significant developments in aeronautics, wingspan, and other
areas of design will certainly create a HAPS-SMBS platform
with higher energy efficiency.

Future HAPS-SMBS wireless network architecture can sup-
port data acquisition, computing, caching, and processing in a
plethora of application domains. Some of them are shown in
Fig. 2 as detailed below.

HAPS-SMBS for IoT applications: It is expected that
in future 5G/B5G networks, HAPS-SMBS will play a key
role in different applications including the internet of things
(IoT). In the past, there have been several research projects
on HAPS; however, they are limited to civil applications, such
as disaster monitoring or earth observation. IoT networks are
characterized by an enormous number of devices each with
low-rate links which are ideal for a single base station with a
wide footprint. Due to its larger coverage, HAPS-SMBS in
future 5G/B5G can support improved coverage for the
realization of diverse outdoor IoT applications in a seamless,
efficient, and cost-effective manner.

HAPS-SMBS for backhauling outdoor small cell BSs:
Although the concept of a small cell base station has been
widely acknowledged and studied for extremely high data rate
coverage in 4G LTE wireless framework and is still perceived
as a 5G key enabler, this concept cannot be realized in a
straightforward manner mainly due to the difficulty and cost
of backhauling a high number of small cell base stations.
Motivated by the recent advances in HAPS and FSO research,
backhauling outdoor small cell BSs can be realized through
FSO and HAPS-SMBS [12], i.e., by placing the outdoor small
cell BSs wherever appropriate without much concern about
backhaul, and then focusing the laser on the HAPS-SMBS for
the backhaul connectivity.

For illustration, Fig. 3 shows the achievable data rate of
an FSO link where it is assumed that the terrestrial small
cell BSs are connected to a HAPS-SMBS through this link.
The achievable data rate of a given FSO link is calculated
according to [12 Eqn. (3)] where the parameters listed in
[12 Table 2] are used to obtain the numerical results. To take
into account the impact of different weather conditions on the
performance, we adopt the approaches developed in [12] and
[13] for fog, rain, and cloud attenuation. From Fig. 3, it can be
observed that the data rates in the range of multi Gb/s can be
achieved in clear weather conditions. It can also be observed
that the achievable data rate is mostly affected by the rain. So
the system may use FSO when there are clear skies or foggy
conditions, and it can switch to RF during rainy conditions.

HAPS-SMBS to cover temporary unpredictable events:
The proposed HAPS-SMBS based wireless network architec-
ture can provide additional coverage in case of temporary
events which are hard to predict. For example, a HAPS-SMBS
can provide additional beams to support the instantaneous
capacity requirements in densely populated areas. Such flash
events normally happen in cities, particularly when there are
large gatherings, which leads to network congestion.

HAPS-SMBS to support agile computational off-
loading: The main idea of computational off-loading is to do
the computations at the network edge near the end user in order
to reduce response time and enable real-time applications.
In the future, as many applications (e.g., augmented reality)
Fig. 2: Representation of target use cases of HAPS-SMBS networks.

Fig. 3: Data rate vs transmit power of a vertical FSO link for different weather conditions. It is assumed that a HAPS-SMBS is placed at a distance of 18 km.

will require high computational capabilities, it is expected that enabling efficient computational offloading will be a necessity. HAPS-SMBS will play a significant role in providing computational services as part of the integrated network.

HAPS-SMBS have more computational power than UE (e.g., aerial UE) and can provide better coverage with LoS links due to their high position which avoids the possibility of disconnection while offloading data.

**HAPS-SMBS as a flying data center:** HAPS-SMBS will also enable the possibility of flying data centers. These data centers can provide a back-up computational facility, that can also be functional in case of emergency scenarios where the ground infrastructure fails to function.

**HAPS-SMBS for coverage holes:** HAPS-SMBS can assist existing terrestrial networks by providing coverage holes through a cost-effective manner. This problem happens when the terrestrial UE received signal strength in an area falls below a predetermined level that is required for robust radio performance due to physical obstructions. For this, a HAPS-SMBS needs to steer a beam in a specific direction. Through their physical advantages, HAPS-SMBS can perform 3D beamforming that enables the creation of separate beams in the three-dimensional space at the same time for different users as shown in Fig. 2. At present, it is widely seen that existing terrestrial networks fail to overcome the coverage holes even in a modern metropolitan area without having a viable access...
HAPS-SMBS can play a key role for the ubiquitous coverage of intelligent transportation systems (ITS)/connected and autonomous vehicle (CAV) paradigms shown in Fig. 4. Recent advances in sensors and the introduction of in-car wireless communication capabilities have paved the way for CAVs that enables unprecedented scenarios for road transportation. Nevertheless, huge data fusion and processing are necessary for many ITS applications. As vehicles are limited in processing capabilities, they may offload the data to cloud or fog computing nodes for delay-tolerant applications require large computation power. However, due to the high mobility of vehicles, data offloading will be interrupted by frequent handovers. In addition, the data processing outcome needs to be delivered through the BS, which is accessible by the vehicle. Fortunately, a HAPS-SMBS can provide both the large area coverage and computational capabilities with low communication delays. Thus, a HAPS-SMBS can eliminate the effect of frequent handovers in vehicular networks. In addition, HAPS-SMBS can be used as a sidelink for vehicle-to-vehicle communications where the terrestrial BS fails to provide enough coverage. Moreover, a HAPS-SMBS can have a wide view of a vehicular network which is essential for coordinating vehicle-to-everything communications, especially for areas with limited infrastructure.

**HAPS-SMBS to cover a massive amount of aerial UE:** Using HAPS-SMBS for coverage can also provide an essential tool for cargo drones that will likely disrupt the retail industry in the near future. As the retail industry is evolving with the possibility of using cargo drones, 3D highways can be expected to serve the cargo package distributions of platooning autonomous drones. Considering 1 delivery/home/day for 1 million homes will require 12 drone launches per second which is the equivalent of approximately 10,000 drones in the air at any given time. To enable reliable connectivity for such a high amount of aerial UEs, a single HAPS-SMBS can be used to cover a city as shown in Fig. 5.

**HAPS-SMBS as an intelligent aerial network enabler:**

HAPS-SMBS can be equipped with powerful processors that can provide computational support for limited-resources aerial network elements. Besides, due to their quasi-stationary positions and large coverage areas, HAPS-SMBS can collect data from large portions of the aerial network and use such data as a real-time input for machine learning (ML) algorithms. In this way, a HAPS-SMBS can dynamically learn about the network status, resources and topology, and with a minimum dependence on terrestrial-based control, a HAPS-SMBS can control and manage the aerial network intelligently.

**HAPS-SMBS as an interface to provide seamless communication to LEO satellites:** LEO satellites move at a very high speed resulting in frequent disconnections and handovers at the terrestrial gateways. Compared to terrestrial gateways, a HAPS-SMBS has a wide upper footprint that can cover many LEO satellites simultaneously. Therefore, it is envisioned that a HAPS-SMBS can act as an interface of the satellite network and provide seamless satellite communication to the aerial and terrestrial networks. In this scenario, HAPS-SMBS will handle the frequent handover of LEO satellites, and if user devices can communicate with a HAPS-SMBS directly then users do not have to use special devices or ground stations to communicate with satellites. In this regard, supervised ML can be utilized by the HAPS-SMBS to learn the mobility patterns of the satellites in order to predict their handover then establish a connection to an approaching satellite before losing the current connection.

**Open Challenges and Future Research**

**Distributed RRM**

The HAPS-SMBS based wireless access architecture we envision has many distinct and even critical characteristics compared to terrestrial networks. The distinct characteristics
may make it inefficient to apply the standards, protocols, and design methodologies that are optimized for radio resource management (RRM) in terrestrial wireless networks in the design of HAPS-SMBS aided VHetNets directly. The RRM algorithms can be operated either in a centralized or distributed fashion. In conventional terrestrial networks, the RRM problems are typically addressed through a centralized approach. However, this may not be a feasible choice for HAPS-SMBS based VHetNets due to issues related to network heterogeneity, computational complexity, cost, spectrum overhead for channel state information (CSI) transmission, and scalability. Although each technology has distinct advantages and drawbacks, distributed RRM technology may help provide HAPS-SMBS aided VHetNets with improved agility and resilience.

In addition, a distributed radio access network (RAN) should be coupled with distributed RRM technology to maximize its full potential. In fact, the concepts of advanced RAN and advanced RRM are inseparable. Besides, distributed RRM should have enough cognition (cognitive radio) to decide when to transmit and which subcarriers to transmit with. Furthermore, the potential of ML should be explored in developing distributed RRM algorithms.

**Capacity Improvement**

There are several ways to improve the capacity of communication networks. Some of them are as follows:

**Spectral efficiency improvement**: MIMO is one of the most promising techniques for improving spectrum efficiency in HAPS networks. However, many challenges have to be addressed for implementing MIMO in HAPS-SMBS. Despite the challenges, there are a considerable number of studies that have investigated the use of MIMO techniques in HAPS communications [14]. In addition, research needs to be undertaken in aerial distributed massive MIMO, where antennas are coordinated from geographically distributed HAPS for improving spectrum efficiency. In particular, 3D MIMO, also known as full dimension MIMO, can yield higher overall system throughput.

Beamforming is also believed to have an important role in addressing the capacity demands of aerial networks at a reduced power level. Beamforming at HAPS-SMBS is more challenging than beamforming at ground BSs, where both the location and target coverage are generally fixed. Some possible directions for research on beamforming at HAPS-SMBS are the following:

- 3D beamforming at HAPS-SMBS for coverage holes and unpredictable hot spots on the ground.
- 3D beamforming at HAPS-SMBS for aerial-UEs (such as cargo drones).

Accurate beam-steering/alignment can be a challenge in moving networks; nevertheless, the quasi-stationarity of a HAPS-SMBS will help in this regard.

**NOMA**: Non-orthogonal multiple access (NOMA) has recently been introduced as an effective approach that can potentially provide spectral efficiency, presenting a promising candidate solution for future radio systems. NOMA can also be exploited to improve spectral efficiency at HAPS-SMBS to cover a massive number of aerial UE; however, the successful operation of NOMA in HAPS-SMBS requires numerous associated challenges to be addressed, including the power coefficient determination in regard to the channel uncertainty of HAPS-SMBS to UE.

**Extension to mmWave bands**: Extending the spectrum to extremely high frequencies, such as mmWave bands, can be regarded as the most efficient proposal for improving transfer rates in HAPS-SMBS. In addition to the bands already dedicated for HAPS usage, for example, 47.2 – 47.5 GHz and 47.9 – 48.2 GHz, ITU during the World Radiocommunication Conference 2019 (WRC-19) congress discussed that the frequency bands 21.4 - 22 GHz and 24.25 - 27.5 GHz can be used by HAPS [15]. The application of mmWave techniques may offer many advantages for HAPS-SMBS, such as higher bandwidth, higher Tx/Rx antenna gain, beamforming and spatial multiplexing gain, placement of a large number of antennas in small dimensions, etc. However, many challenges have to be addressed for HAPS-SMBS mmWave communication networks, including the large coverage with mmWave.

**Network Management/Control**

The need for the joint communication, control, computing, and caching in a HAPS-SMBS to meet the intrinsic requirements of envisioned applications raises unprecedented challenges in the network management.

There have been gradual developments to make communication networks more autonomous, self-organizing, self-configuring, and self-sustaining. To support these developments, potential solutions have been introduced in the literature; network slicing (NS), software-defined network (SDN), network function virtualization (NFV), are among them. The VHetNets architecture is highly dynamic and heterogeneous. The exploitation of NS, SDN, and NFV in the presence of a HAPS-SMBS should be explored to facilitate network reconfiguration and improve network agility and resilience. For example, the HAPS NS should consider dynamic spectrum slicing to avoid underutilization or overutilization. Furthermore, the application of machine learning techniques to derive an in-network solution in HAPS-SMBS systems is a promising research topic. The ability of having in-network solution will eliminate the need for direct human intervention on many operation levels and allow HAPS systems to make intelligent decisions in a collaborative manner.

**Interference Management/Control**

HAPS were previously deployed in isolation, so there was no or few problems of interference. In metropolitan areas, one of the key challenges of deploying HAPS is interference management. In this case, owing to the simultaneous data transmission from HAPS-SMBS with other segments of the integrated network, more interference will be generated which may result in a higher link outage probability. To access the impact of the aggregated interference produced by HAPS-SMBS on the integrated VHetNet architecture, proper interference analysis and management of interference is required. Furthermore, intelligent interference management is necessary,
which can be achieved through implementing ML algorithms that can learn and adapt to changes in network environments. Thus, interference management through beamforming and frequency reuse can be done in an intelligent way.

**HAPS Constellations and Inter-HAPS Networking:**

We also envision deploying a network (constellation) of interconnected HAPS-SMBSs whenever necessary. For instance, the 7,800 km long trans-Canada highway from the Pacific Ocean to the Atlantic can be served by a linear HAPS constellation towards a coast-to-coast intelligent transportation system. Coordinating a HAPS network through ground stations would not be a feasible choice due to response delays, and a ground station with its limited footprint cannot have communication coverage to all the HAPS network. Therefore, we envision that HAPS networks will be self-organized with either centralised or distributed control and management system. In the centralized approach, a HAPS is elected to be the manager while the others are followers. In the distributed approach, the available HAPS in a network need to negotiate and coordinate in distributing the communication tasks in order to avoid interference, wasting resources, or overlapping footprints. In this regard, a comprehensive study of the HAPS constellation design methodology and inter-HAPS networking with proper interference management becomes critical.

**CONCLUSION**

In this article, we shed light on the potential opportunities and target use cases of HAPS-SMBS aided wireless access architecture. We pointed out that, while research on HAPS goes back to the late 1990s, the concept has attracted new attention in recent years, both in academia and industry, as a promising solution in future wireless networks. This momentum is fueled by the ever-increasing demand from wireless networks and also by advances in solar panel efficiency, battery energy density, lightweight composite materials, autonomous avionics, and antennas. We illustrated that the proposed VHet-Nets architecture empowered by HAPS-SMBS nodes will enable the network to increase the overall throughput, improve coverage, and also to provide a platform to perform the near-user computation to significantly reduce the end-to-end delays. Furthermore, HAPS-SMBS nodes will also enable the network to address unpredictable congestion instances as well as coverage holes in populated areas.

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