HAPS: Connect the unconnected

White paper

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High-altitude platform stations (HAPS) are used to supplement terrestrial networks and extend coverage to remote areas. Technology advances have enabled HAPS to stay afloat in the stratosphere for several months as base station platforms with the communication payload powered by solar energy. HAPS can provide connectivity for remote areas not served by terrestrial networks, global coverage for IoT devices, and services for the public safety and transportation industries. At a typical altitude of 20 km, HAPS systems can cover a large service area with a higher throughput and lower latency compared to satellite links. In this short paper, we present an overview of a 5G NR-based (new radio) HAPS communications system comprised of both service and feeder links that can serve a large coverage area. We also show the achievable capacity and coverage of the HAPS system at sub-6 GHz carrier frequency.

Contents

Introduction

Non-terrestrial networks (NTN) are comprised of satellites (GEO, MEO and LEO), HAPS and unmanned aerial vehicles (UAVs). In this paper we focus on HAPS, a concept that has been explored since the 1990s using airplanes and balloons as platforms for base stations at altitudes ranging between 18 to 24 km [1] [2]. HAPS has the potential of providing high data rates for a large coverage area with significantly lower latency than satellite links. It also has the economic advantage of lower development and deployment costs for the same coverage over satellite and terrestrial networks.

In the stratosphere, the HAPS vehicle is able to harvest abundant solar power and continuously operate for months without turbulence [3]. Commercial applications of HAPS have begun to roll out, initially targeting the areas under-served by terrestrial networks [4] [5], but may later expand to broader regions to provide other services, such as mobile broadband, internet of things (IoT) connectivity, terrestrial network backhauling, public safety, disaster relief and communications for the maritime and transportation industries.

With the arrival of 5G mobile communication, HAPS and satellites are being considered as alternative platforms for 5G new radio (NR) base stations or repeaters using regenerative and transparent (a.k.a. bent-pipe) architectures respectively [6] [7]. The 3GPP standardization organization has completed the study phase of supporting NTN in the 5G NR wireless standard, and the initial specification is targeted for Release 17. Also being investigated is the possibility of HAPS using millimeter wave (mmWave) spectrum to provide service link connectivity to NR user equipment (UE) [8]. Lower frequency bands are likely to be used, however, for mobile data services in near-term deployments.

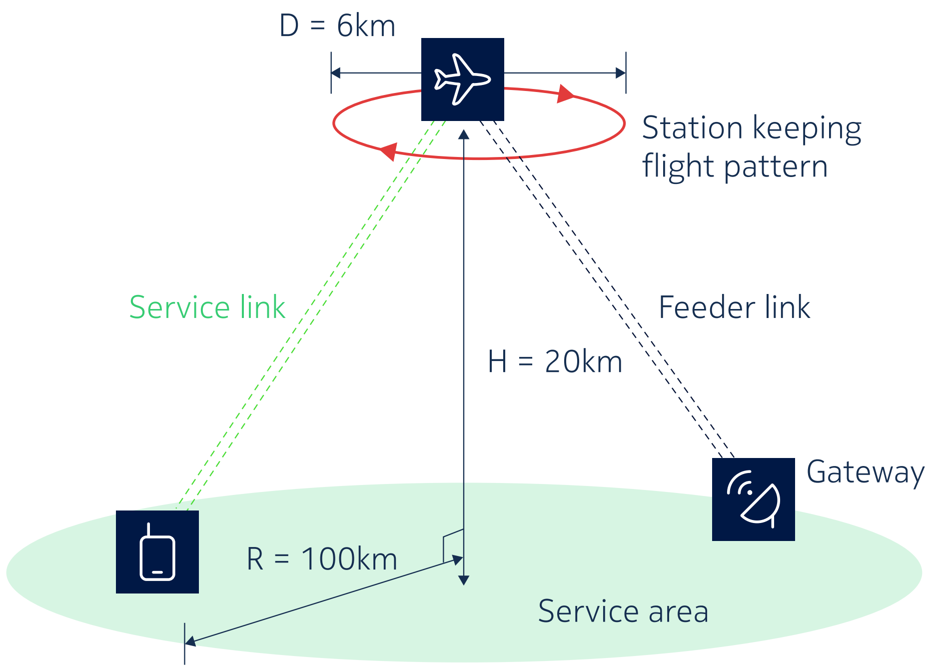
In this paper, we provide a brief overview of HAPS use cases, architecture and performance.

HAPS overview and architecture

HAPS will support various use cases utilizing different carrier frequencies and bandwidth such as LTE, cmWave NR, and mmWave NR. Use cases include wide-coverage backhaul for non-terrestrial group mobility at around 10 Gbps, high-speed wireless backhaul for industrial networks at around 1 Gbps, and MBB/IoT for wide-area coverage (e.g., rural area connectivity or disaster relief) at tens of Mbps [9].

Figure 1 shows the typical scenario where the HAPS is flying at an average altitude of 20 km at a speed of 80–120 km/hr in a repetitive flight pattern known as station keeping. It maintains a 6 km diameter circle to provide consistent coverage on the ground. Data services are provided to UEs via the HAPS service link over the 4G/LTE or 5G NR air interface at sub-6 GHz carrier frequency. The HAPS is also connected to one or more ground gateway stations by the feeder link as the backhaul for the aggregated traffic of the service link.

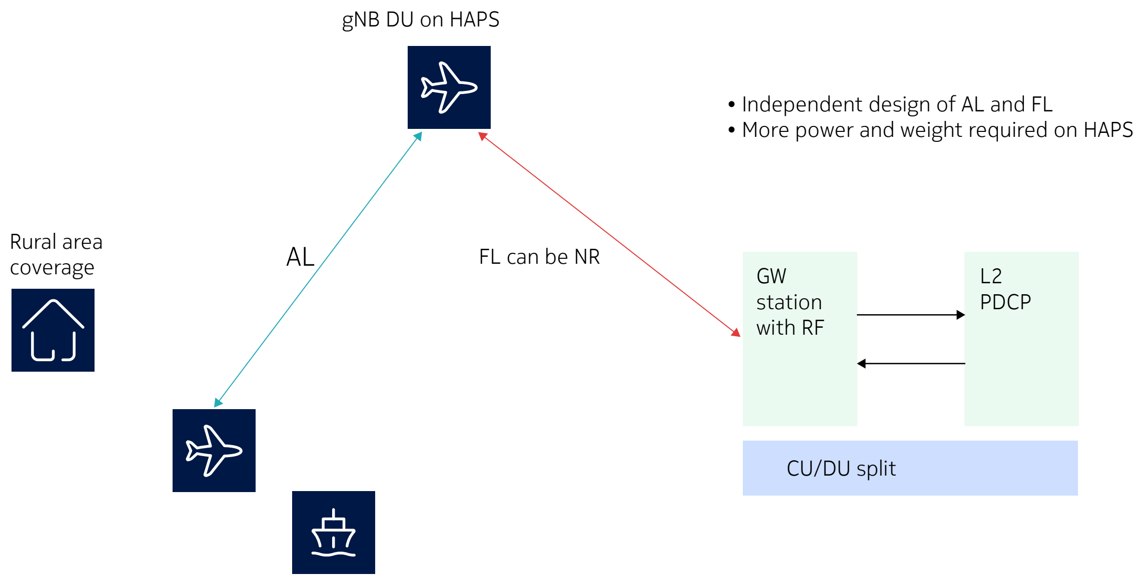
Figure 1. Typical operating scenario of airplane-based HAPS



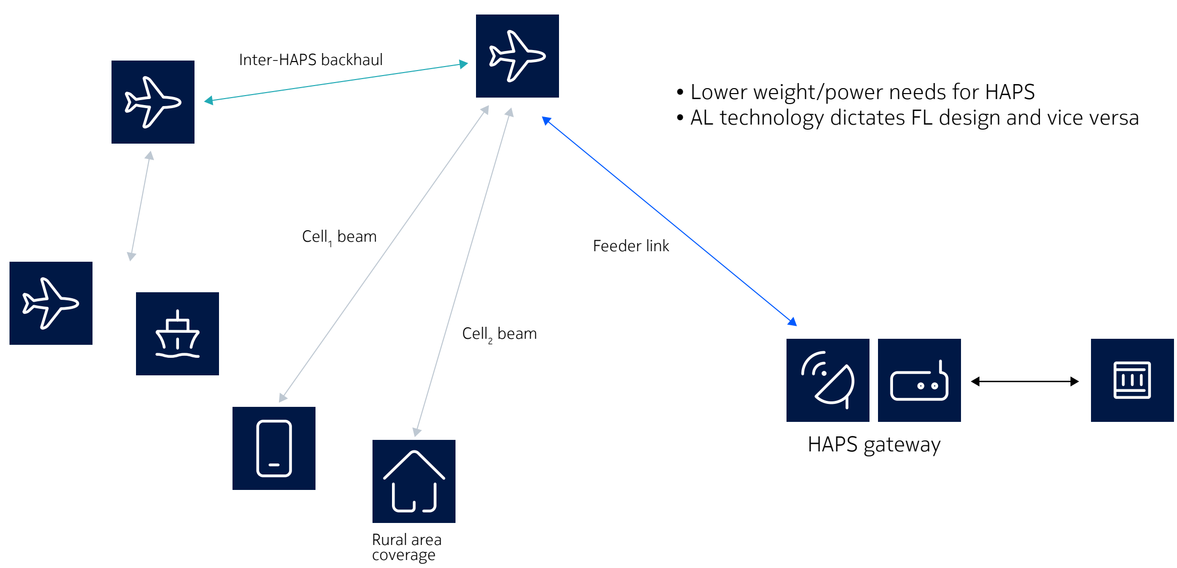
The two different architectures envisioned for HAPS, namely regenerative and bent pipe, are illustrated in figure 2. In the full regenerative architecture, HAPS carries the entire baseband unit (BBU) including user scheduling and packet encoding and decoding, while in the bent pipe case the HAPS acts as a repeater with the gNB on the ground. The selection of preferred architecture depends on power consumption, weight and size limitations of the HAPS platform, taking into consideration the achievable capacity and coverage. It is also desirable to reuse terrestrial network hardware components — baseband units (BBU), transceiver units (TXRU) and antenna modules — in the payload design.

Figure 2. Two architectures for HAPS

(a) Regenerative architecture: HAPS as a base station



(b) Bent-pipe architecture: HAPS as a repeater



HAPS performance

In order for the HAPS to achieve the largest possible terrestrial coverage, the antenna array needs to provide sufficient gain for a wide range of angles. We propose a hexagonal array structure composed of six side panels and an underneath panel facing downward as illustrated in figure 3. The panel at the bottom has the boresight pointing straight down, illuminating a region right under the HAPS. The other six side panels face outward with an inclination angle to cover areas further away from the center over the entire azimuth domain. This design effectively sectorizes the large service area to seven cells— one center cell surrounded by six outer cells.

Figure 3. Hexagon antenna array for HAPS

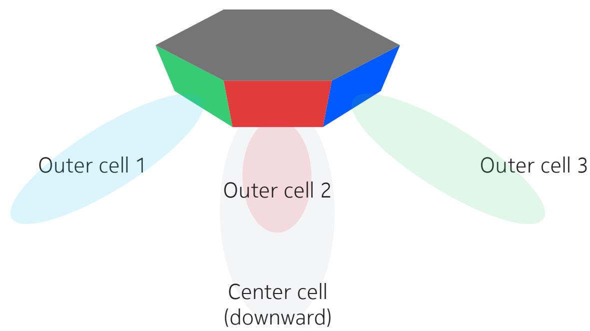


Figure 4 shows the downlink throughput at 2.1 GHz carrier frequency with 20 MHz bandwidth as a function of distance from the center of the service area based on link budget. The low throughput point at around 19 km marks the border between the center cell and an outer cell. Beyond this point in the outer cell coverage, the throughput largely depends on the azimuth angle. The highest throughput for a given distance appears along the boresight direction $\Phi=0$. Similarly, figure 5 shows the uplink throughput at 1.8 GHz frequency with 1 MHz channel bandwidth, assuming that interference power is 3 dB below the noise power. A small outage area at the far end of cell edge can be observed.

Figure 4. DL throughput at 2.1 GHz with 20 MHz bandwidth

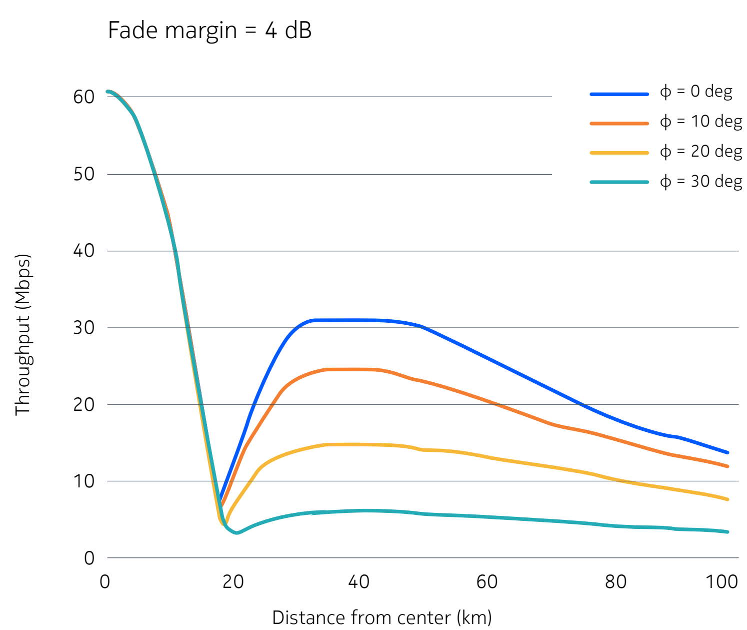
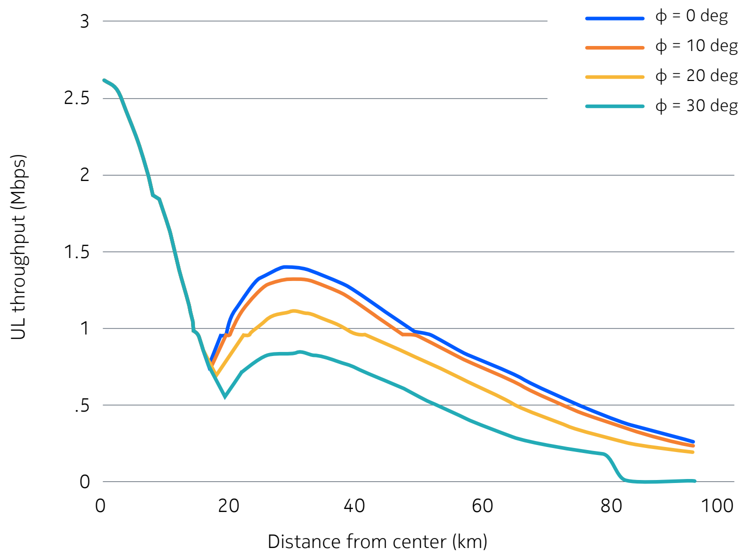


Figure 5. UL throughput at 1.8 GHz with 1 MHz bandwidth



HAPS system performance is evaluated through system-wide Monte Carlo simulations for the entire coverage area. The system performance is characterized by two metrics: mean system SE, which indicates the average system capacity, and cell edge SE, which is defined as the fifth percentile user SE and characterizes the data rate of the edge users.

Table 1 shows the downlink and uplink spectral efficiency of the 7-cell HAPS system at a carrier frequency of around 2 GHz [9]. Due to the limited UE power (23 dBm) and low UE antenna gain (0 dBi), uplink has a lower spectral efficiency.

Table 1. Spectral efficiency of a HAPS system

	Spectral efficiency (bit/s/Hz/cell)	
	Mean SE	**Cell edge SE**
Downlink	1.40	0.32
Uplink	0.61	0.08

Conclusion

HAPS is a promising technology for the next generation of mobile communications and is capable of providing significant coverage from the stratosphere over a long period of time. As a supplement to terrestrial networks, HAPS not only helps connect remote areas but also provides global coverage for IoT devices and services in public safety, mines, agriculture and many other fields. Regenerative and bent-pipe architectures provide multiple design options to suit the platform weight and power limitation, desired coverage and capacity, and feeder link spectrum availability. We have presented a feasible system design that can cover an area with 100 km radius and demonstrated that a good level of capacity can be achieved with a DL/UL 1.4/0.61 bits/sec/Hz/cell spectral efficiency for 7 cells at carrier frequency 2 GHz.

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