CAN STRATOSPHERIC VEHICLES HELP EASE THE GROWING DEMAND FOR EFFICIENT HIGH-SPEED WIRELESS COMMUNICATIONS?

Broadband

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It has always been a dream of communications engineers to be able to develop a wireless network that, while covering a wide area, would also have low propagation delay and little multipath fading. Recently, a new way for providing wireless communications services emerged. Based on airships or aircraft positioned in the stratosphere at altitudes from 17 to 22km, the technology is known as high altitude platforms (HAP) or stratospheric platforms (SPF).

Although the idea of raising balloons is not new, it was only in the middle of the 20th century that it started to attract interest from the scientific and industrial communities, mostly due to the appealing characteristics that high aerial vehicles offer. In 1960, a giant balloon called Echo was launched to passively reflect broadcasts from the Bell Laboratories facility at Crawford Hill.

HAPs have most of the advantages of both terrestrial and satellite systems, while they avoid some of their drawbacks. The most important similarities and differences among HAP, terrestrial wireless and satellite systems are summarised in table 1. The most important disadvantages of HAPs lie in the immature airship technology and the monitoring of the platform's movement.

Angel Technologies' Halo (Proteus 9) aircraft. Fuelled, manned; payload: ≈1 ton

TO MAN OR NOT TO MAN

Throughout the evolution of HAPs three types of vehicles can be identified:

- *Unmanned* airships with propulsion systems. These are normally huge (100m long with a payload of more than 800kg) solar-powered balloons filled with helium, which can be semi-rigid or non-rigid[1]. The basic construction material is the resilient, helium leak-proof laminated plastic. Lightweight solar cells (< $400gr/m^2$) lie on the upper surfaces of the airship
- *Unmanned aircraft*[2-5]. Also known as high altitude long endurance (HALE) platforms, these solar-powered aircraft are smaller than airships, they cannot carry fairly heavy payload and are power-limited, especially during long-night periods. A variant are fuelled unmanned aircraft, often referred to as unmanned aerial vehicles (UAVs), which generally fly at modest altitudes and are used for military short-time surveillance
- *Manned aircraft* are conventional fuelled aircraft with a payload of approximately one ton[6,7]

AeroVironment/NASA's Helios aircraft (US). Solar-powered, unmanned; wingspan: 75 m; payload: 50-100 kg

from heaven

Table 2 provides a general comparison of these types of vehicles. The altitudes of HAPs proposed in most studies fall within 17 and 22km. The main reason for this range selection is twofold: first, these altitudes are above aviation air lanes; secondly, average wind speed is sufficiently low (See fig 1), while the extremely low ambient density of greater altitudes would render the placement of a vehicle unfeasible. Airships are more susceptible to wind or pressure variations and they have to compensate for the drift. However, it is rather difficult to finely control the attitude of an airship remotely. Although aircraft are not so prone to winds, they cannot remain stationary and they fly on a tight circle.

SPECTRUM ALLOCATION AND NETWORK DESIGN

Several frequency bands over 24GHz have been allocated to LMDS type of services. ITU has allocated the 47·2-47·5GHz and 47·9-48·2GHz bands for HAP applications. In Asia the 28/31GHz band was instead assigned, as the 47/48GHz band is susceptible to rain attenuation.

HAPs can also be deployed for some 3G services. The 1885-1980MHz, 2010-2025MHz and 2110-2170MHz bands in Region 1 and 3, and 1885-1980MHz and 2110-2160MHz in Region 2 are allocated to the 3G wireless communications. Table 3 summarises the current available frequency bands for HAP applications.

Just as in satellites, HAPs can act as relay stations (often called "transparent"), or can incorporate a level of functionality themselves (referred to as "processing"), mostly depending on the available onboard power. Several studies[8-11] have proposed a cellular architecture for broadband communications through HAPs (See fig 2) as a way to increase network capacity. Each platform will be connected to terrestrial networks through a ground gateway, while a backhaul link can be provided via an LEO/MEO/GEO satellite system. Interplatform links can also be established in order to unify remote areas. Chains of HAPs can also be placed above ocean ship lanes12 offering typical maritime services such as voice, data, video, paging and broadcasting.

An appealing feature of HAPs is their ability to move in order to cover spatial and temporal traffic fluctuations[13, 14]. Although movement results in link deterioration on the far edge of the coverage area, considerable bandwidth

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European Space Agency airship and ATG's Stratsat (UK, inset)

Issue	HAPs	Terrestrial wireless	Satellite
Propagation delay	Low	Low	High in GEO (and MEO to some extent)
Typical station coverage	Up to 200km	A few kilometres	>1000km for LEO and ≈34% of the earth surface for GEO
Typical cell diameter	1-10km	0·1-1km	>500km
Deployment time	Flexible: one platform and ground support are enough for initial commercial services	Substantial initial build out required	LEO/MEO: Service cannot start before the entire system is deployed
System growth	Capacity increase through spot-beam resizing and additional platforms	Cell-splitting to add capacity, requiring system reengineering; easy equipment update/repair	System capacity increased only by adding satellites; hardware upgrade only with replacement of satellites
Radio channel "quality"	Free-space-like channel with Ricean fast fading at distances comparable to terrestrial	Rayleigh fading limits distance and data rate; path loss up to 50 dB/decade	Free-space-like channel with Ricean fading; path loss roughly 20 dB/decade; GEO distance limits spectrum efficiency
Health concerns with radio emission from handsets	Power levels like in terrestrial systems	Low-power handsets minimise concerns	High-power handsets due to large path losses (possibility to alleviate by careful antenna design)
Indoor coverage	Substantial	Substantial	Generally not available
Cost	Varies	Unspecified (more than $50m, but less than the cost required to deploy a terrestrial network with many basestations)	More then $200m for a GEO system. Measured in billions for LEO systems (Iridium cost $5bn)

Table 1 Comparison of HAP, terrestrial wireless and satellite systems

	Airships (unmanned)	Solar-powered unmanned aircraft	Manned aircraft
Size	Length 150-200m	Wingspan 35-70m	Length ≈30m
Total weight	≈30ton	≈1ton	≈2·5ton
Power source	Solar cell (+fuel cell)	Solar cell (+fuel cell)	Fossil fuel
Environmentally friendly	–	–	–
Response in emergency	–	–	–
Flight duration	≈5 years	Unspecified (≈6 months)	≈8 hours
Position keeping (radius)	≈1km	≈3km	≤10km
Mission payload	1000-2000kg	50-300kg	≈1000kg
Power for mission	≈10kW	≈3kW	≈20kW
Examples	Japan, Korea, China, ATG, Lockheed Martin, Skystation, ESA	Helios, Pathfinder Plus (AeroVironment), Heliplat (HeliNet project)	HALO (Angel Technologies)

Table 2 Comparison of airships, solar-powered unmanned and manned aircraft

savings can be achieved for a limited maximum displacement distance. An interesting architecture considered the use of macrocells and microcells[15], with the latter being able to follow temporal traffic variations.

To be immediately profitable, HAPs can be used for niche market applications, providing services to users not currently served by terrestrial wireless, fibre, cable or xDSL systems. However, as the technology matures, mass-market applications could soon become available.

IT'S RAINING BAD

Rain has a direct impact on the quality of the system, as it attenuates the signal by absorbing or scattering radiation (See fig 3). The higher the frequency, the higher the attenuation due to rain. The geometry of rain scattering interference is presented in fig 4.

Strategies for ameliorating the detrimental effects of rain are required to ensure high availability levels of the provided services[9,16,17]. A localised rain outage can be avoided by applying a space, time or frequency diversity technique. Regarding rain scattering interference, narrow beamwidth antennas result in improved CIR (carrier to interference ratio). Moreover, an increase in the number of reuse channels reduces interference by reducing the number of neighbouring co-channel cells affected by rain.

AVOIDING INTERFERENCE

Interference is a very important issue in any communication system. In HAPs there are two kinds of interference to consider: that originating from users of the HAP network itself, and that from/to terrestrial or satellite

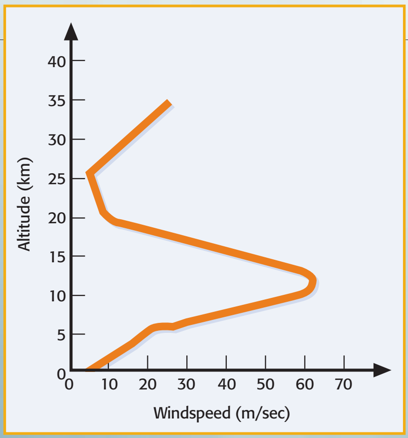


Fig 1 Wind velocity with respect to altitude

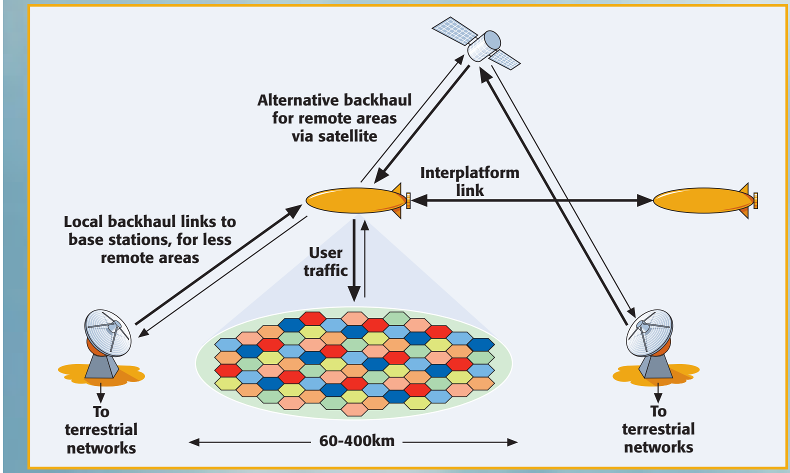


Fig 2 Architecture for broadband communications via HAPs

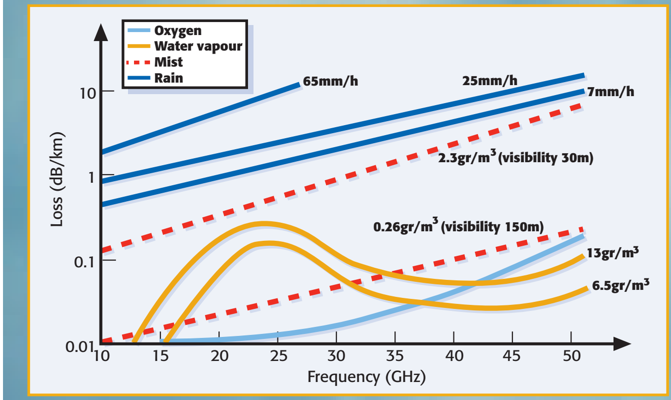


Fig 3 Attenuation due to rain, mist, water vapour and oxygen

systems sharing the same or adjacent frequency bands. The latter can be further divided into four cases of interference paths: between HAP ground stations and other terrestrial or satellite earth stations; between HAP ground stations and space stations (i.e. satellites); between HAP onboard stations and other terrestrial stations; and finally between HAP onboard stations and satellites.

The interference levels always affect the supported number of users[15] and should be mitigated. Interference originated from co-channel users can be alleviated if a cluster with many cells is applied[16, 18]. Furthermore, CIR is dependent on the spaced antenna profile[19]. Regarding interference to GEO satellite systems[20], it can be reduced by improving the radiation pattern of the onboard antenna via beam shaping (See fig 5). Meanwhile, in the case of HAP ground stations interfering to other ground services, interference decreases as the minimum elevation angle increases (See fig 6).

CRUCIAL ELEMENT

The antenna system is one of the most important performance factors in an HAP configuration. Miura and Suzuki[21] summarised the required functions for a successful broadband HAP antenna in five rules:

- Use of high radio frequency in order to secure sufficient bandwidth
- Directional antenna with a high gain to cope with attenuation in high frequencies
- Multibeam antenna that accommodates 100 beams or more – both for transmission and reception – to cover views as wide as 120° or more from the stratosphere, with a high gain and to achieve effective use of the frequencies involved
- Cancellation of the influences of altitude/position variations of the HAP on the footprint by means of beam control
- Reduced weight, size and power consumption of the mission payload

Two types of multibeam antennas were said to meet the above requirements: multibeam horn (MBH) antennas of the mechanical-drive type, and digital beamforming (DBF) antennas of the electronic-scanning type (See fig 7).

The main features of the MBH antenna are the broad bandwidth (depending on existing technology), the excellent wide-angle characteristics of gain and axial ratio and the comparatively low development expense. However, this antenna is considered not to be particularly suitable to a large-scale multibeam antenna application, because it becomes oversized, making the gimbal difficult to rotate. Generally, this antenna lacks flexibility compared to the DBF option.

In the DBF antenna, a beam is formed by a combination of the array antenna and spatial digital signal processing. It is an intelligent, next-generation antenna, referred to as "smart antenna" or "software antenna". It supports automatic acquisition, tracking, accurate beam steering, interference separation and so on, by performing spatial parallel processing of signals received from the ground-user stations, thereby forming an antenna pattern. Since there is no mechanical-drive component, this antenna is considered to be suitable for multi-element, large-scale, multibeam formation.

SO WHO'S QUEUING UP FOR IT?

One of the attractive features of HAP systems is their rapid deployment time. They are well suited for "short-term applications". For example, they can be used to cover a seasonal or one-time event, such as the Olympic Games or a pop concert. They can also be used for providing temporary services in disaster relieve operations. For the bulk of emergency management applications,

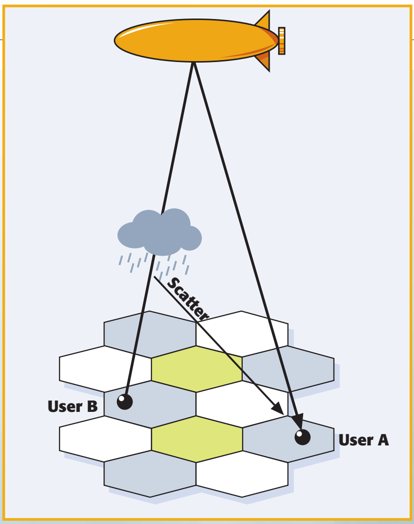


Fig 4 Geometry of rain scatter. The radiation beamed towards user B is scattered by the rain and causes co-channel interference to user A, in another cell

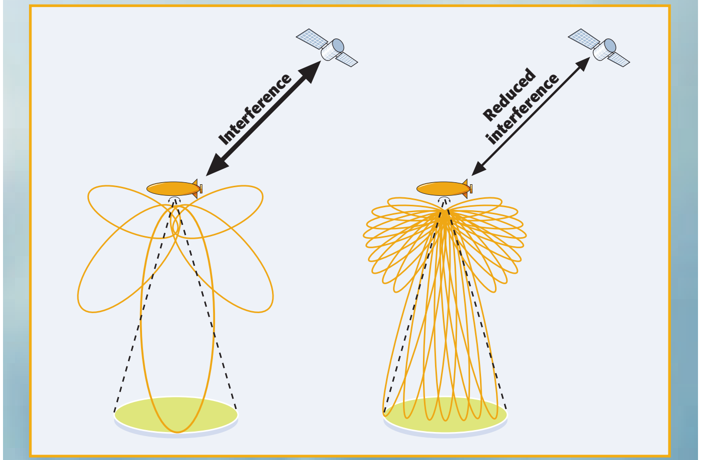


Fig 5 Improvement of radiation pattern of onboard antenna by beam shaping

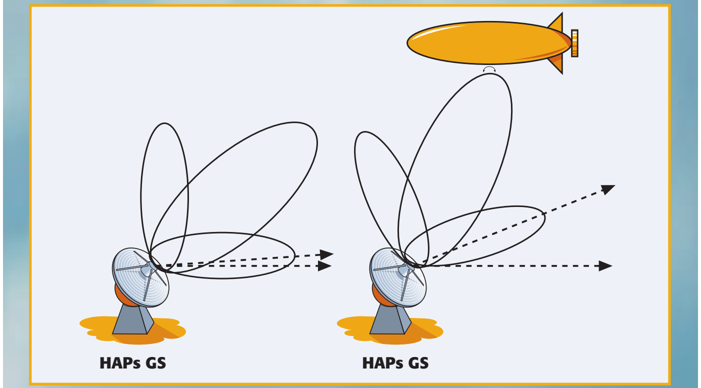


Fig 6 Increase of minimum operational elevation angle

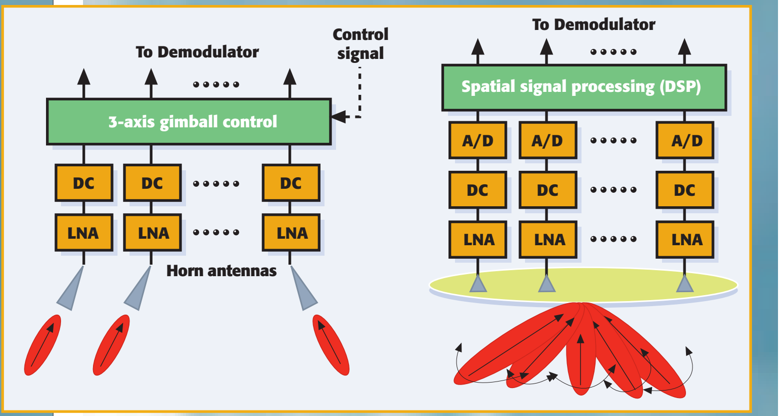


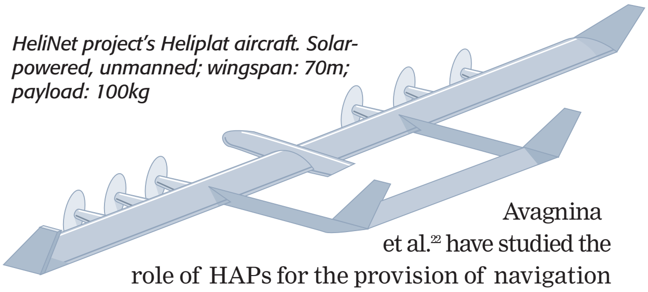
Fig 7 Basic configuration of prototype multibeam antennas (receiving mode); (a) multibeam horn; (b) digital beamforming

unmanned aircraft hold significant advantages over airships by virtue of their immediate response time.

HAPs would also be capable of delivering very wideband Internet access (e.g. 10Mbit/s downlink and 2Mbit/s uplink), entertainment video and audio, videoconferencing, cellular telephony, broadband LMDS services and access provision to digital networks (i.e. ISDN).

Two scenarios can be conceived. The first one employs the HAP as a "backup" basestation covering a wide rural area, partially served by terrestrial basestations. The HAP in that case acts as an "umbrella". The second scenario has the HAP providing a full-service coverage of a wide rural area, where no terrestrial network is active.

Their flexibility allows HAPs to be used not only for carrying telecommunications payloads, but also for remote sensing – earth observation; pollution monitoring; meteorological measurements; real-time monitoring of seismic or coastal regions and terrestrial structures; traffic monitoring and control; reconnaissance and surveillance missions; and agriculture support.



HeliNet project's Heliplat aircraft. Solar-powered, unmanned; wingspan: 70m; payload: 100kg

Avagnina et al.[22] have studied the role of HAPs for the provision of navigation and positioning services. High altitude platforms can have an active role in global navigation satellite systems (GNSS), as augmentation systems to GPS or Galileo. But their real advantage emerges from the fact that they can be used for providing *both* communication and navigation services, while they could also be integrated with terrestrial networks such as GSM and UMTS.

Recently, the attractive features of HAPs led to the funding of some relevant projects. HeliNet[2, 9, 16] is a project based on a solar-powered, unmanned aircraft (a HALE platform named Heliplat) funded by the European Commission. Several applications from remote sensing to telecommunications to the provision of localisation/navigation services for various transport means are being examined.

A Japanese national project[21, 23] – led by the Science and Technology Agency, the Ministry of Posts and Telecommunications and the Yokosuka Research Centre – aims to produce an integrated network of some 15 airships. It is being designed to provide broadband and broadcasting services to most of Japan.

Through funding support from NASA, AeroVironment has developed an unmanned, solar-powered aircraft named Helios. It will provide a telecommunications platform from the stratosphere – hence its SkyTower name[3, 4]. In

Global Hawk aircraft (US). Fuelled, unmanned; altitude: 65,000 feet; speed: 454mph

collaboration with AeroVironment, its subsidiary SkyTower and NASA, the Communications Research Laboratory and Telecommunications Advancement Organisation divisions of Yokosuka Research Centre successfully tested the world's first digital high-definition television (HDTV) broadcast transmission from the stratosphere using Pathfinder Plus, an unmanned, solar-powered vehicle manufactured by AeroVironment, in June 2002. The test was followed by an IMT-2000 mobile application demonstrating video telephony.

The HALO (high altitude long operation) network project by Angel Technologies[6,7] will serve as a broadband wireless metropolitan network based on existing technology, with a manned aircraft operating as a solitary "hub". Provided services will include T1 access, ISDN, Web browsing, high-quality videoconference, large file transfers and Ethernet LAN bridging.

With their characteristic wide-area coverage and low propagation delay, capable of providing a variety of services beyond just telecommunications, HAPs seem to represent a dream come true for those communications engineers working on the "ideal wireless system". But in spite of their outstanding features, several factors have so far hampered the deployment of these systems. Further development in antenna, airship and unmanned aircraft technologies are necessary, as well as convincible demonstrations of HAPs usefulness.

Real applications are yet to flourish – no doubt hindered at present by an obvious shortfall in the available technology. However, it is reasonable to believe that, given a few years, the first networks will start to populate the skies. ■

Frequency band	*Areas*	*Link direction*	*Services*	*Services to be shared with*
47·9-48·2GHz *47·2-47·5GHz*	*Global*	*Up and downlink*	*Fixed service*	• *Fixed and mobile services* • *Fixed satellite service (uplink)* • *Radio astronomy band neighbouring*
31·0-31·3GHz	*12 Asian countries*	*Uplink*	*Fixed service*	• *Fixed and mobile services* • *Space science service in some areas* • *Space science service band (passive) neighbouring*
27·5-28·35 GHz	*12 Asian countries*	*Downlink*	*Fixed service*	• *Fixed and mobile services* • *Fixed satellite service (uplink)*
1885-1980 MHz *2010-2025 MHz* *2110-2170 MHz*	*Regions 1 and 3*	*Up and downlink*	*IMT-2000*	• *Fixed and mobile services (in particular, terrestrial IMT-2000 and PCS)*
1885-1980 MHz *2110-2160 MHz*	*Region 2 (North and South America)*	*Up and downlink*	*IMT-2000*	• *Fixed and mobile services (in particular, terrestrial IMT-2000 and PCS)*

Table 3 Frequency bands allocated for HAP communications

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