High-Altitude Platforms for Wireless Communications

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High-altitude platforms for wireless communications

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The demand for high-capacity wireless services is bringing increasing challenges, especially for delivery of the 'last mile'. Terrestrially, the need for line-of-sight propagation paths represents a constraint unless very large numbers of base-station masts are deployed, while satellite systems have capacity limitations. An emerging solution is offered by high-altitude platforms (HAPs) operating in the stratosphere at altitudes of up to 22 km to provide communication facilities that can exploit the best features of both terrestrial and satellite schemes. This paper outlines the application and features of HAPs, and some specific development programmes. Particular consideration is given to the use of HAPs for delivery of future broadband wireless communications.

1 The challenge for wireless communications

As the demand grows for communication services, wireless solutions are becoming increasingly important. Wireless can offer high-bandwidth service provision without reliance on fixed infrastructure and represents a solution to the 'last mile' problem, i.e. delivery directly to a customer's premises, while in many scenarios wireless may represent the only viable delivery mechanism. Wireless is also essential for mobile services, and cellular networks (e.g. 2nd generation mobile) are now operational worldwide. Fixed wireless access (FWA) schemes are also becoming established to provide telephony and data services to both business and home users.

The emerging market is for broadband data provision for multimedia, which represents a convergence of high-speed Internet (and e-mail), telephony, TV, video-on-demand, sound broadcasting etc. Broadband fixed wireless access (B-FWA) schemes aim to deliver a range of multimedia services to the customer at data rates of typically at least 2 Mbit/s. B-FWA should offer greater capacity to the user than services based on existing wirelines, such as ISDN or xDSL, which are in any event unlikely to be available to all customers. The alternative would be cable or fibre delivery, but such installation may be prohibitively expensive in many scenarios, and this may represent a barrier to new service providers. B-FWA is likely to be targeted initially at business, including SME (small–medium enterprise) and SOHO (small office/home office) users, although the market is anticipated to extend rapidly to domestic customers.

However delivering high-capacity services by wireless also presents a challenge, especially as the radio spectrum is a limited resource subject to increasing pressure as demand grows. To provide bandwidth to a large number of users, some form of frequency reuse strategy must be adopted, usually based around a fixed cellular structure. Fig. 1*a* illustrates the cellular concept, where each hexagon represents a cell having a base-station near its centre and employing a different frequency or group of frequencies represented by the colour. These frequencies are reused only at a distance, the reuse distance being a function of many factors, including the local propagation environment and the acceptable signal-to-interference-plus-noise ratio.

To provide increased capacity, the cell sizes may be reduced, thus allowing the spectrum to be reused more often within a given geographical area, as illustrated in Fig. 1*b*. This philosophy leads to the concept of microcells for areas of high user density, with a base-station on perhaps every street corner. Indeed, taking the concept to its extreme limit, one might envisage one cell per user, the evident price in either case being the cost and environmental impact of a plethora of base-station antennas, together with the task of providing the backhaul links to serve them, by fibre or other wireless means, and the cost of installation.

Pressure on the radio spectrum also leads to a move towards higher frequency bands, which are less heavily congested and can provide significant bandwidth. The main allocations for broadband are in the 28 GHz band (26 GHz in some regions), as well as at 38 GHz[1]. Existing broadband schemes may be variously described as LMDS (Local Multipoint Distribution Services) or MVDS (Multipoint Video Distribution Services)[2,3]; these are

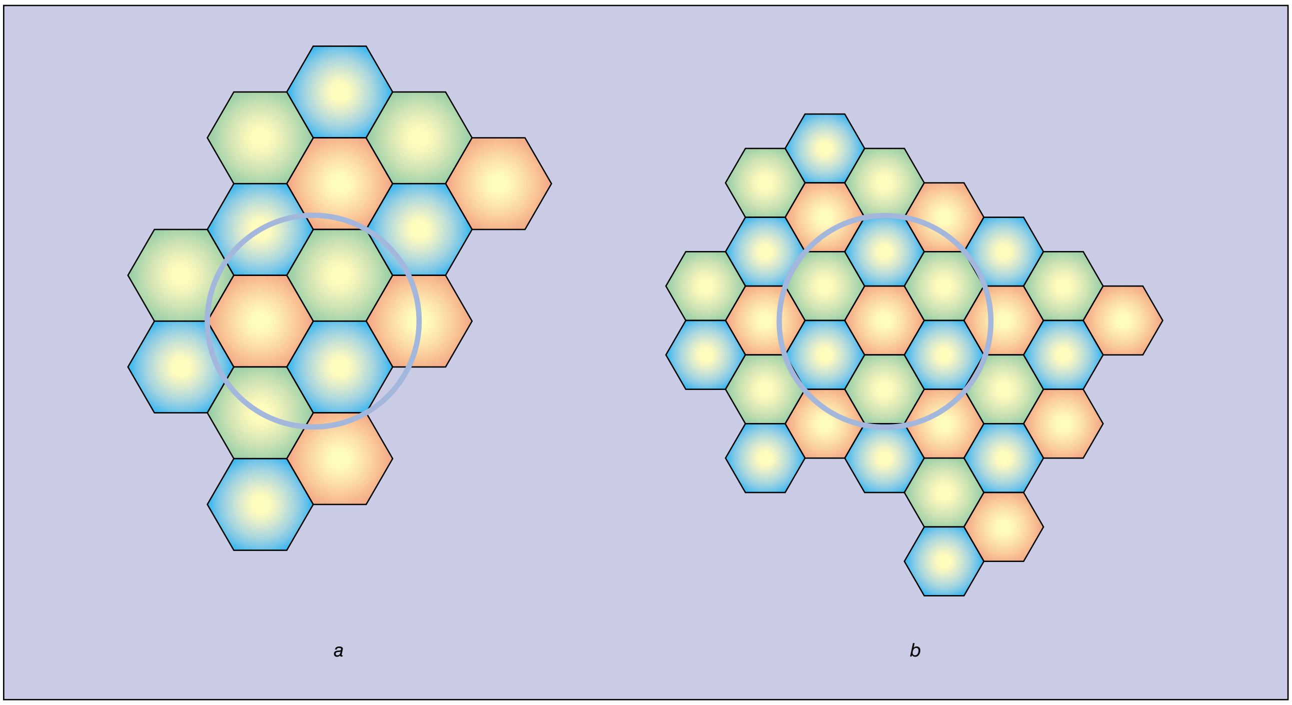


Fig. 1 Cellular frequency reuse concept. In *b* the smaller cells provide greater overall capacity as frequencies are reused a greater number of times within a given geographical area.

flexible concepts for delivery of broadband services, although they may be encompassed in the generic term B-FWA, or simply BWA.

The use of these millimetre wavelengths implies line-of-sight propagation, which represents a challenge compared with lower frequencies. Thus local obstructions will cause problems and each customer terminal needs to 'see' a base-station; i.e. a microcellular structure is essential for propagation reasons. This again implies a need for a very large number of base-stations.

A solution to these problems might be very tall base-station masts with line-of-sight to users. However, these would be not only costly but also environmentally unacceptable. An alternative delivery mechanism is via satellite, which can provide line-of-sight communication to many users. Indeed, broadband services from geostationary (GEO) satellites are projected to represent a significant market over the next few years[4]. However, there are limitations on performance due partly to the range of c. 40 000 km, which yields a free-space path loss (FSPL) of the order of 200 dB, as well as to physical constraints of on-board antenna dimensions. The latter leads to a lower limit for the spot-beam (i.e. cell) diameter on the ground, and these minimum dimensions constrain the frequency reuse density and hence the overall capacity. Additionally, the high FSPL requires sizeable antennas at ground terminals to achieve broadband data rates. A further downside is the lengthy propagation delay over a geostationary satellite link of 0·25 s, which not only is troublesome for speech but also may cause difficulties with some data protocols.

Low earth orbit (LEO) satellites may circumvent some of these limitations in principle, but suffer from complexities of rapid handover, not only between cells but also between platforms. The need for large numbers of LEO satellites to provide continuous coverage is also a significant economic burden, and such schemes have yet to prove commercially successful.

2 Aerial platforms: a solution?

A potential solution to the wireless delivery problem lies in aerial platforms, carrying communications relay payloads and operating in a quasi-stationary position at altitudes up to some 22 km. A payload can be a complete base-station, or simply a transparent transponder, akin to the majority of satellites. Line-of-sight propagation paths can be provided to most users, with a modest FSPL, thus enabling services that take advantage of the best features of both terrestrial and satellite communications.

A single aerial platform can replace a large number of terrestrial masts, along with their associated costs, environmental impact and backhaul constraints. Site acquisition problems are also eliminated, together with installation maintenance costs, which can represent a major overhead in many regions of the world.

The platforms may be aeroplanes or airships (essentially balloons, termed 'aerostats') and may be manned or unmanned with autonomous operation coupled with remote control from the ground. Of most interest are craft designed to operate in the stratosphere at an altitude of typically between 17 and 22 km, which are referred to as high-altitude platforms (HAPs)[2,3,5–7]. While the term HAP may not have a rigid definition, we take it to mean a solar-powered and unmanned aeroplane or airship, capable of long endurance on-station—e.g. several months or more. Another term in use is 'HALE'—High Altitude Long Endurance—platform, which implies crafts capable of lengthy on-station deployment of perhaps up to a few years.

HAPs are now being actively developed in a number of programmes world-wide, and the surge of recent activity reflects both the lucrative demand for wireless services and advances in platform technology, such as in materials, solar cells and energy storage.

Balloons

The earliest aerial platforms were balloons, whose history goes back to the time of the ancient Chinese. In the West, the first major use of lighter-than-air craft was the Montgolfier brothers' manned hot air balloon in France in 1783. Subsequent development of balloons remained largely for military application, although their application for communication purposes seems to have been very limited. In the early 20th century, rigid, powered airships were developed by the Zeppelin company in Germany for passenger transport, and these proved a remarkable engineering feat, enabling passengers to travel from Europe to South America. Unfortunately, this era came to an abrupt end with the Hindenburg disaster at Lakehurst, USA, in 1937. Whatever the precise cause of that disaster, use of the highly flammable hydrogen to fill the airship was no longer considered acceptable, and with the development of commercial air travel after the Second World War large airships seemed to be consigned to history.

Subsequent activity was mainly confined to hot-air balloons for recreational purposes, small balloons for meteorological use, and tethered aerostats ('balloons on strings'). The latter may operate up to at least 5000 m altitude[8], although there are evident implications for air-traffic safety and their use is highly restricted, the majority operating at much lower altitudes. (One major application of tethered aerostats is surveillance. Large numbers are deployed along the US–Mexican border to detect unauthorised crossings[9].)

The past few years have seen a resurgence of interest in balloons and airships, with technology developments such as new plastic envelope materials that are strong, UV resistant and leak-proof to helium, which is now almost universally used instead of the much cheaper hydrogen. Such hi-tech airships have featured in high-profile attempts to circumnavigate the globe (e.g the Breitling Orbiter[10]). And a new airship, the Zeppelin NT, a low-altitude craft, was launched by the Zeppelin company in 2000, exactly 100 years after its first airship, with a view to the scenic tourism market (Fig. 2)[11]. Another major project, albeit low altitude, is Cargolifter[12] (Fig. 3); this large airship is proposed to be some 250 m long and aims to provide a 'flying crane' service for transportation of heavy goods over difficult terrain.

Fig. 2 The Zeppelin NT airship, launched in June 2000 (Courtesy of Zeppelin Luftschifftechnik GmbH)[10]

But a major business goal remains that of developing a stratospheric HAP capable of serving communication applications economically and with a high degree of reliability. Whether an airship or an aeroplane, a major challenge is the ability of the HAP to maintain station-keeping in the face of winds. An operating altitude of between 17 and 22 km is chosen because in most regions of the world this represents a layer of relatively mild wind and turbulence. Fig. 4 illustrates a typical jet-stream wind profile vs. height; although the wind profile may vary considerably with latitude and with season, a form similar to that shown will usually obtain. This altitude (>55 000 ft) is also above commercial air-traffic heights, which would otherwise prove a potentially prohibitive constraint.

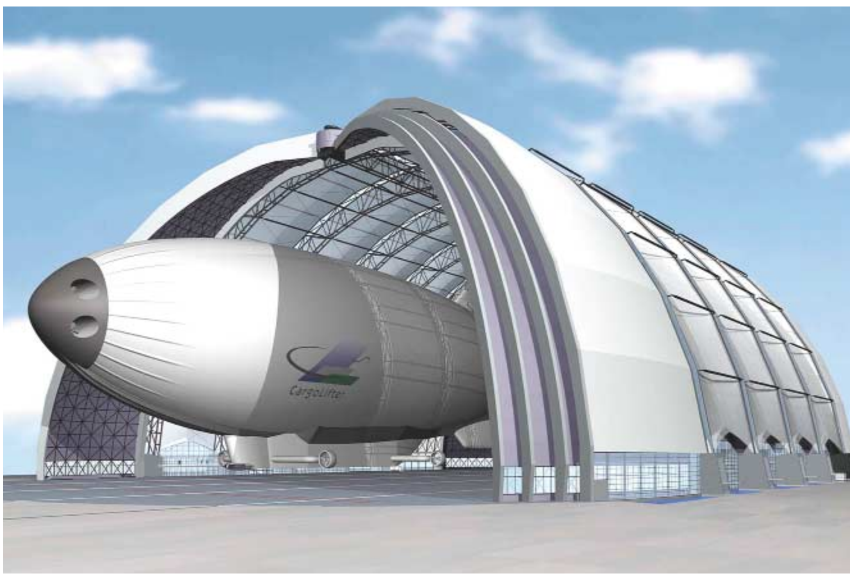


Fig. 3 Artist's impression of Cargolifter (Courtesy of Cargolifter GmbH)[11]

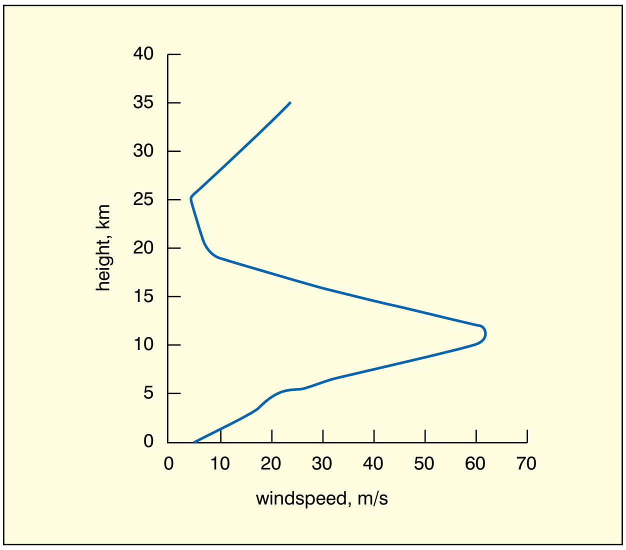


Fig. 4 Windspeed profile with height. Values vary with season and location, but generally follow this rough distribution. (Source: NASA)

Airship HAPs

Proposed implementations of airships for high-altitude deployment use very large semi-rigid or non-rigid helium-filled containers, of the order of 100 m or more in length. Fig. 5 shows an artist's impression of a HAP from Lindstrand Balloons. Electric motors and propellers are used for station-keeping, and the airship flies against the prevailing wind. Prime power is required for propulsion and station-keeping as well as for the payload and applications; it is provided from lightweight solar cells in the form of large flexible sheets, which may weigh typically well under 400 g/m^2 and cover the upper surfaces of the airship. Additionally, during the day, power is stored in regenerative fuel cells, which then provide all the power requirements at night.

The overall long-term power balance of a HAP is likely to be a critical factor, and it will be the performance and ageing of the fuel cells that are likely to determine the achievable mission duration. However, this is mitigated by the fact that it is relatively easy to bring HAPs back to earth, unlike satellites, for service and/or replacement of the fuel cells as well as for other maintenance or upgrading.

One of the major HAP airship projects is the Japanese SkyNet[13]. Funded substantially by the Japanese government, and led by Yokosuka Communications Research Laboratory, this project aims to produce an integrated network of some 15 airships to serve most of Japan, providing broadband communication services operating in the 28 GHz band, as well as broadcasting.

A range of airships is being developed by Advanced Technologies Group, of Bedford, UK[14], at one time in collaboration with SkyStation International of the USA[15], who proposed an airship 150 m in length supporting a communications payload of up to 800 kg. HAP airships are also being proposed by Lindstrand Balloons[16]. A novel design of HAP comprising several smaller airships joined together in an 'Airworm' configuration is being developed by The University of Stuttgart[17,18]: this sausage-like formation aims to provide the lift while avoiding some of the structural and aerodynamic problems associated with very large airships.

Aeroplane HAPs

Another form of HAP is the unmanned solar-powered plane, which needs to fly against the wind, or in a roughly circular tight path. Again, the prime challenge is likely to be the power balance, the craft having to be able to store sufficient energy for station-keeping throughout the night. The most highly-developed such craft are those from AeroVironment in the USA, whose planned Helios plane has a wing-span of 75 m; their Pathfinder and Centurion programmes[19] (Fig. 6) have already demonstrated flight endurance trials at up to 25 km altitude (80 000 ft). Funded initially by NASA, these programmes have the goal of long-endurance operation for commercial communications and other applications.

HeliPlat[20] is a solar-powered craft being developed under the auspices of Politecnico di Torino in Italy, as part of the HeliNet Project[21,22] funded by the European Commission under a Framework V initiative. HeliNet is examining many issues, from the aeronautical aspects—a scale size prototype plane is being developed—to three possible applications: broadband telecommunication services, environmental monitoring and vehicle localisation. The broadband communications aspects are being led by the University of York[23] and are described further in a companion paper in this issue[24].

But the HAP project currently most near-market for communications is a manned aircraft with pilots operating on an 8-hour shift. Angel Technologies' HALO project[25] employs the specially designed Proteus aircraft (Fig. 7) operating at altitudes of 16–18 km (51 000–60 000 ft) to deliver

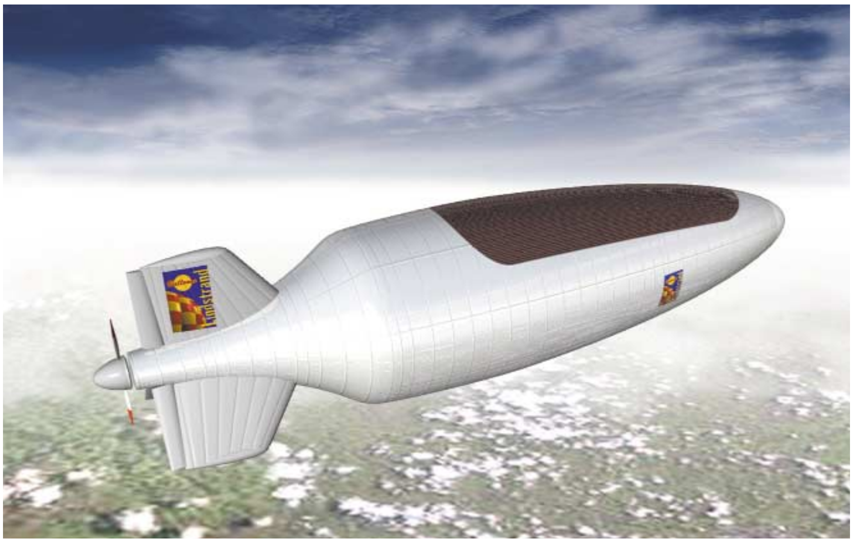


Fig. 5 Lindstrand HAP concept (Courtesy of Milk Design and Lindstrand Balloons Ltd.[15])

broadband communication services over an area up to 40 km in diameter. The aircraft will maintain a quasi-stationary position by flying in a roughly circular path with a typical diameter of less than 13 km. The communications payload uses a pod below the fuselage housing up to 125 microwave antennas. The aircraft is well proven, and this may be considered a relatively low-risk solution, although ultimate commercial success will depend upon the economics of operation.

Fig. 6 Helios. AeroVironment's craft has a wing span of 75 m and aims to operate up at 100 000 ft under solar power (Photo: NASA Dryden/Tom Tschida)

Some other aerial platforms

Another category of aerial platforms is the UAV—Unmanned Aerial Vehicle. This refers typically to small fuelled unmanned aircraft, having short mission durations and operating at generally modest altitudes. The main use of UAVs is for military surveillance, with some smaller craft being considered almost as disposable. The application of UAVs as communication relay nodes seems to be limited, no doubt due largely to their relatively short endurance. Larger military UAVs include Global Hawk[26] and Predator[27] (Fig. 8), which can support large payloads and fly long distances, but have not generally been considered cost-effective for normal communication provision.

Finally, the simplest and most available aerial platform is a tethered aerostat. This is an airship on a cable, whose length may reach up to 5 km or more. Tethering partially deals with the major problem of station-keeping, although platform movement is still an issue. Power and communications backhaul may also be provided through the tether. The evident challenge is the hazard presented to air traffic, and although some aerostats are deployed in aircraft exclusion zones, their general application may be more suited to less developed regions. An important current programme is that of Platforms Wireless International, which is developing a tethered aerostat for use in Brazil at an altitude of 4·6 km (15 000 ft)[28]. Its ARC (Airborne Relay Communications) system aims to deliver a range of cellular communication services to over 125 000 subscribers.

3 Communication applications

Fig. 9 depicts a general HAP communications scenario. Services can be provided from a single HAP with up- and down-links to the user terminals, together with backhaul links as required into the fibre backbone. Inter-HAP links may serve to connect a network of HAPs[29], while links may also be established if required via satellite directly from the HAP.

The coverage region served by a HAP is essentially determined by line-of-sight propagation (at least at the higher frequency bands) and the minimum elevation

Fig. 7 HALO Proteus aircraft. Note the pod for the payload underneath. (Courtesy of Angel Technologies Corp.)

Fig. 8 Predator, a military UAV (Courtesy of General Atomics Aeronautical Systems Inc.)

angle at the ground terminal. A practical lower elevation limit for BWA services might be 5°, while 15° is more commonly considered to avoid excessive ground clutter problems. From 20 km altitude above smooth terrain, 5° implies an area of c. 200 km radius or 120 000 km^2, although for many service applications, e.g. to a city or suburban area, such wide coverage may not be required or appropriate.

There is then opportunity to subdivide this area into a large number of smaller coverage zones, or cells, to provide large overall capacity optimised through frequency reuse plans. The size, number, and shape of these cells is now subject to design of the antennas on the HAP, with the advantage that the cell configuration may be determined centrally at the HAP and thus reconfigured and adapted to suit traffic requirements. Indeed, the HAP architecture lends itself particularly readily to adaptive resource allocation techniques, which can provide efficient usage of bandwidth and maximise capacity.

Compared with geostationary satellite services, the cells can be considerably smaller, since the minimum spot-beam size from a satellite is constrained by the on-board antenna dimensions. Higher capacity with HAPs is also facilitated by the much more favourable link budgets compared to satellites, since the HAP is at relatively close range; this represents a power advantage of up to about 34 dB compared to a LEO satellite, or 66 dB compared to a GEO satellite. And compared with terrestrial schemes, a single HAP can offer capacity equivalent to that provided by a large number of separate base-stations; furthermore the link geometry means that most obstacles will be avoided.

BWA applications

The principal application for HAPs is seen as B-FWA, as described above, providing potentially very high data rates to the user. The frequency allocation for HAPs at 47/48 GHz offers 2 × 300 MHz of bandwidth, which might be apportioned 50:50 to user and backhaul links, and again 50:50 to up- and down-links. (An exception might be where links are mainly used for Internet traffic, which would warrant an asymmetric apportionment.) Studies undertaken based on the HeliNet scenario propose a scheme with an overall coverage region per

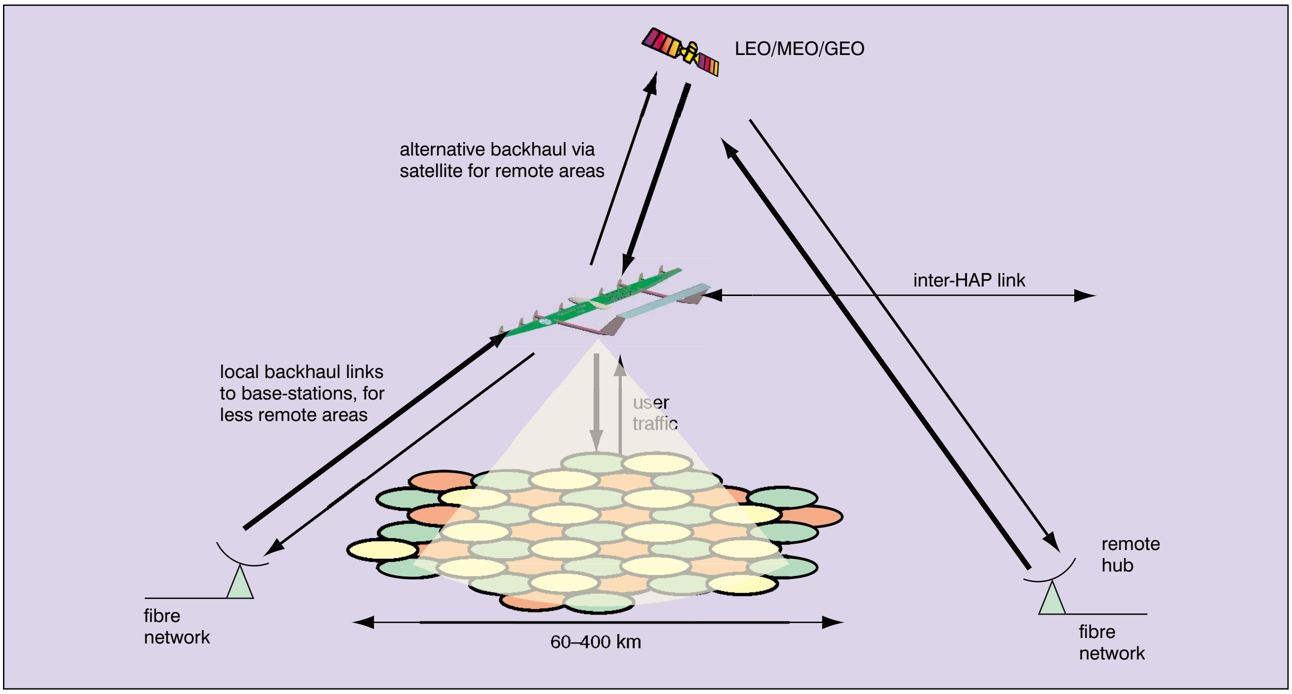


Fig. 9 HAP communications scenario

HAP of diameter 60 km, having 121 cells, each with a nominal ground diameter of 5 km[24]. Downlink HAP power is 1 W per cell, and this can support data rates of up to 60 Mbit/s which is well within the bandwidth required per cell of 25 MHz when using 16-QAM or higher order modulation schemes. The total payload throughput in this conservative demonstrator example is in excess of 7 Gbit/s, although the HALO scheme is claiming 100 Gbit/s[25].

It is evident that the backhaul requirements are as stringent as the user links themselves, since in principle what goes up must come down. No single wireless link can provide the full backhaul capacity, so this will also need to be handled via a cellular scheme. Thus there will need to be a number of distributed backhaul ground-stations, although these can be far fewer than the number of user cells served since the backhaul links will be higher specification and handle greater capacity, with higher-order modulation schemes. Fortunately these ground-stations can nevertheless be modest and unobtrusive and their location within the coverage region is non-critical; they will probably be situated on the roofs of buildings.

3G/2G applications

HAPs may offer opportunity to deploy next generation (3G) mobile cellular services, or indeed current (2G) services[30], and use of the IMT-2000 (3G) bands from HAPs has been specifically authorised by the ITU. A single base-station on the HAP with a wide-beamwidth antenna could serve a wide area, which may prove advantageous over sparsely populated regions. Alternatively, a number of smaller cells could be deployed with appropriate directional antennas. The benefits would include rapid roll-out covering a large region, relatively uncluttered propagation paths, and elimination of much ground-station installation.

HAP networks

A number of HAPs may be deployed in a network to cover an entire region. For example, Fig. 10 shows several HAPs serving the UK. Inter-HAP links may be accomplished at high EHF frequencies or using optical links; such technology is well established for satellites and should not present major problems.

Developing world applications

HAPs offer a range of opportunities for services in the developing world. These include rural telephony, broadcasting and data services. Such services may be particularly valuable where existing ground infrastructure is lacking or difficult.

Emergency or disaster applications

HAPs can be rapidly deployed to supplement existing services in the event of a disaster (e.g. earthquake, flood), or as restoration following failure in a core network.

Military communications

The attractions of HAPs for military communications are self-evident, with their ability for rapid deployment.

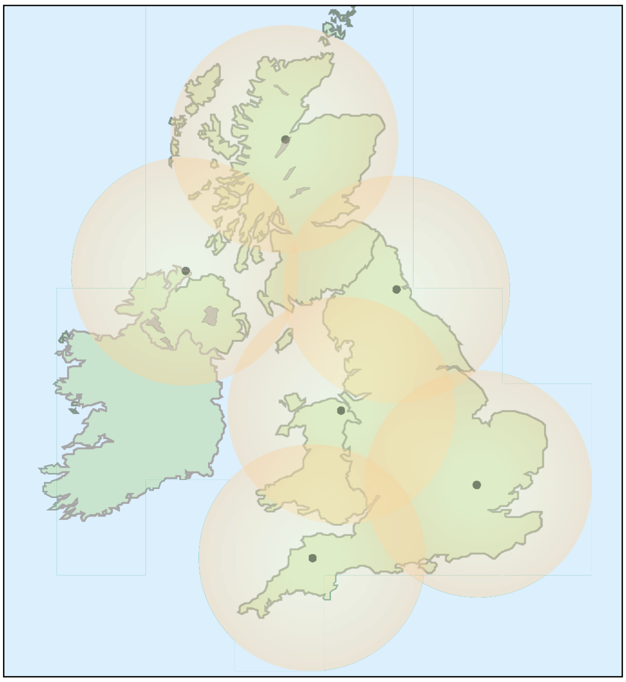


Fig. 10 Coverage of the UK with a network of HAPs (approxiately line-of-sight propagation)

They can act as nodes within existing military wireless networks, or as 'surrogate' satellites—in this case carrying a satellite payload and operating with conventional satcom terminals. Besides the ability to provide communications where none might exist, there is a benefit in that their relatively close range demands only limited transmit power from the ground terminals, and this provides enhanced LPI (Low Probability of Interception) advantages.

Within military scenarios, airships proper are currently confined largely to use at very low heights for mine clearance operations, and their application for communications remains to be fully exploited. Although it might be thought that airship HAPs are vulnerable to enemy attack, they do possess an advantage in that despite their large size their envelope is largely transparent to microwaves and they present an extremely low radar cross-section.

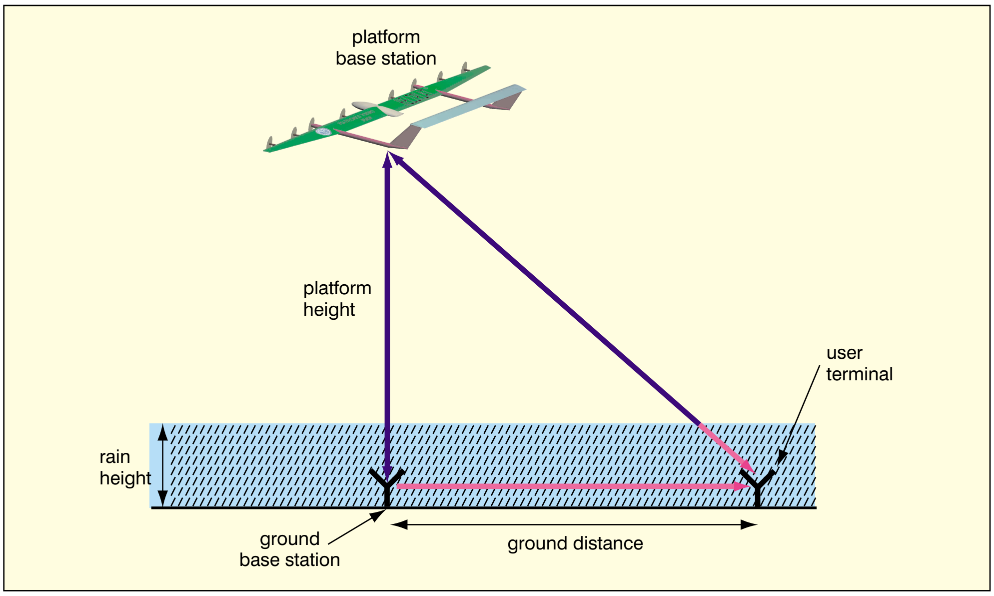
4 Advantages of HAP communications

HAP communications have a number of potential benefits, as summarised below.

Large-area coverage (compared with terrestrial systems). The geometry of HAP deployment means that long-range links experience relatively little rain attenuation compared to terrestrial links over the same distance, due to a shorter slant path through the atmosphere. At the shorter millimetre-wave bands this can yield significant link budget advantages within large cells (see Fig. 11).

Flexibility to respond to traffic demands. HAPs are ideally suited to the provision of centralised adaptable resource allocation, i.e. flexible and responsive frequency reuse patterns and cell sizes, unconstrained by the physical location of base-stations. Such almost real-time

Fig. 11 Slant path in rain. The attenuated portion may be shorter from a HAP than from a terrestrial base-station.



adaptation should provide greatly increased overall capacity compared with current fixed terrestrial schemes or satellite systems.

Low cost. Although there is to date no direct experience of operating costs, a small cluster of HAPs should prove considerably cheaper to procure and launch than a geostationary satellite or a constellation of LEO satellites. A HAP network should also be cheaper to deploy than a terrestrial network with a large number of base-stations.

Incremental deployment. Service may be provided initially with a single platform and the network expanded gradually as greater coverage and/or capacity is required. This is in contrast to a LEO satellite network, which requires a large number of satellites to achieve continuous coverage; a terrestrial network is also likely to require a significant number of base-stations before it may be regarded as fully functional.

Rapid deployment. Given the availability of suitable platforms, it should be possible to design, implement and deploy a new HAP-based service relatively quickly. Satellites, on the other hand, usually take several years from initial procurement through launch to on-station operation, with the payload often obsolete by the time it is launched. Similarly, deployment of terrestrial networks may involve time-consuming planning procedures and civil works. HAPs can thus enable rapid roll-out of services by providers keen to get in business before the competition.

Furthermore, there is little reason why prepared HAPs should not be capable of being launched and placed on-station within a matter of days or even hours. This will facilitate their use in emergency scenarios. Examples might include: natural disasters; military missions; restoration where a terrestrial network experiences failure; overload due to a large concentration of users, e.g. at a major event.

Platform and payload upgrading. HAPs may be on-station for lengthy periods, with some proponents claiming 5 years or more[15]. But they can be brought down relatively readily for maintenance or upgrading of the payload, and this is a positive feature allowing a high degree of 'future-proofing'.

Environmentally friendly. HAPs rely upon sunlight for their power and do not require launch vehicles with their associated fuel implications. They represent environmentally friendly reusable craft, quite apart from the

Table 1: Comparison of broadband terrestrial, HAP and satellite services: typical parameters

	Terrestrial (e.g. B-FWA)	HAP	LEO satellite (e.g. Teledesic[31])	GEO satellite
Station coverage (typical diameter)	<1 km	up to 200 km	>500 km	up to global
Cell size (diameter)	0·1–1 km	1–10 km	c. 50 km	400 km minimum
Total service area	spot service	national/regional	global	quasi-global
Maximum transmission rate per user	155 Mbit/s	25–155 Mbit/s	<2 Mbit/s up 64 Mbit/s down	155 Mbit/s
System deployment	several base stations before use	flexible	many satellites before use	flexible, but long lead time
Estimated cost of infrastructure	varies	$50 million upwards?	c. $9 billion	>$200 million
In-service date	2000	2003–2008?	2005	1998

potential benefits of removing the need for large numbers of terrestrial masts and their associated infrastructure.

Table 1 summarises a comparison between terrestrial, HAP and satellite delivery for broadband services.

5 Some issues and challenges

The novelty of HAP communications calls for some new concepts in terms of delivery of services (e.g. B-FWA), raising critical issues for development. And the platforms themselves present some challenges and potential problems.

System level requirements. HAP networks for broadband communication service delivery will require a rethink of the basic design of cellular-type services, with development focusing upon the frequency planning of different spot beam layouts, which are subject to wide angular variations and changes in link length, and frequency reuse patterns for both user and backhaul links. The network architecture will need to exploit opportunities of inter-terminal switching directly on the HAP itself as opposed to on the ground, and the use of inter-HAP links to achieve connectivity.

Propagation and diversity. Services from HAPs have been allocated frequencies by the ITU in the millimetre-wave bands, at 47/48 GHz (and also at 28 GHz in ITU Region 3—predominantly Asia). Propagation from HAPs is not fully characterised at these higher frequencies: rain attenuation is significant in these bands, so one of the main requirements is to develop rainfall attenuation and scattering statistics. This will allow appropriate margins to be included and highlight any problems with frequency reuse plans developed at the system level. An important objective is to determine the most appropriate diversity techniques (e.g. space, time and frequency) for each traffic type.

Modulation and coding. In order to optimise network capacity, suitable modulation and coding schemes will be required to serve the broadband telecommunication services, with specified QoS (Quality of Service) and BER (Bit Error Rate) requirements, applicable under different link conditions. Adaptive techniques will provide overall optimum performance, using low-rate schemes involving powerful forward error correction (FEC) coding when attenuation is severe, up to high-rate multilevel modulation schemes when conditions are good.

Resource allocation and network protocols. Channel assignment and resource allocation schemes will need to be developed for the HAP scenario, which is essentially different from either a terrestrial or a satellite cellular scenario. The schemes have to be tailored to multimedia traffic and also take into account the system topology and choice of modulation/coding scheme. The most appropriate medium access control (MAC) and network protocols will be selected as a starting point. For BWA services it is likely that a modified version of the broadband standards IEEE 802.16/ETSI BRAN could be used. Integration with terrestrial and/or satellite architectures will also require careful planning.

Antennas. Antenna technology will be critical to BWA from HAPs. A large number of spot beams will be required, and these may be produced either by an ensemble of horn antennas or some form of phased array. Sidelobe performance is an important issue, which will affect intercell interference and, ultimately, system capacity. At a planned frequency of 48 GHz, this is demanding technology both for the HAP-based antenna and also for ground terminals.

Platform station-keeping and stability. The ability of a HAP to maintain position reliably in the face of variable winds is a major challenge and will critically affect the viability of communication services. HAP positioning is likely to be represented as a certain statistical probability of remaining within a particular volume, e.g. a location cylinder. Example figures from the HeliNet programme relate to 99% and 99·9% platform availability within specified location limits, and clearly such parameters are not readily compatible with provision of communication services having traditional 'four nines' availability such as 99·99%. Some new thinking will be required, perhaps based on the use of multiple HAPs and diversity techniques.

Stability is another critical issue. Inevitably, there will be roll, pitch and yaw of the platform, due to turbulence in the stratosphere; in this regard, larger craft are likely to exhibit greater stability. Antenna pointing on the HAP may be maintained either through the use of a mechanically stabilised sub-platform, which may be bulky, or though use of electronic steering of an array antenna. This latter technique offers considerable potential, but is also technologically demanding, especially at the millimetre-wave bands likely to be used for broadband services.

Handoff. Most HAP schemes are proposing to use multiple spot beams over the coverage area, yielding capacity through frequency reuse. Although a BWA network architecture is likely to have mainly fixed users, handoffs may occur as the antenna beams move due to platform motion, depending on the HAP stabilisation techniques. This is in contrast to conventional mobile cellular schemes, where handoff is invariably due to motion of the user. The size of the cells on the ground, and the physical stability of the HAP antenna pointing, will govern how often these will occur. It may be possible to use fixed antennas on the HAP, and to accommodate motion simply through handoff procedures (which could be quite rapid). However, delay and jitter limitations for future multimedia services (especially video) may impose much more stringent constraints on the handoff process than with conventional 2G or 3G services, and this is a topic of current research.

Should ground-based antennas be fixed or steerable? HAPs will vary in position, both laterally and vertically: the latter perhaps deliberately so in order to optimise altitude to minimise prevailing winds. This movement results in changes of look angle from the ground terminal, which can be used to determine whether fixed or steerable ground-based antennas are required. If the angular variation is greater than the beamwidth of the antenna, which will be a function of the gain required to

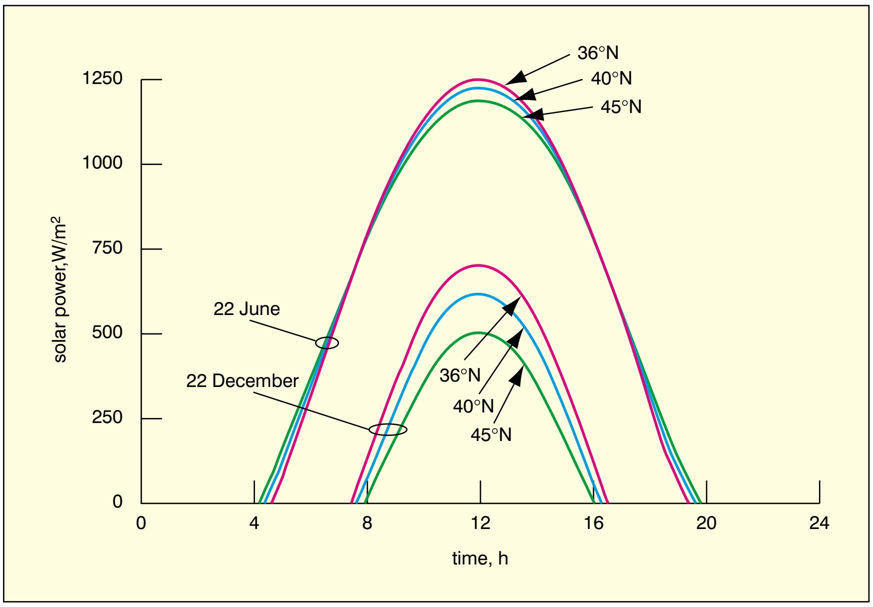


Fig. 12 Solar power flux on a HAP at a height of 17 km as a function of seasonal extreme, time and latitude

operate the link, then it is necessary to use a steerable ground terminal antenna. The greatest angular variation is immediately below the HAP; however, at this close range wider antenna beamwidths may be feasible due to favourable link budgets. Changes in vertical height may be more significant to antennas at the periphery of coverage if these are correspondingly higher gain, and hence narrower beamwidth. Clearly, the requirement for steerable antennas will increase terminal costs, but may be necessary to achieve high link capacity.

Payload power. An important distinction between the different types of HAP is the power available to the payload. Typically an airship may have in excess of 20 kW available for the payload, due to the large surface area on which to deploy solar cells. Planes powered by conventional fuel sources (e.g. the HALO scheme by Angel Technologies) will similarly have high power available. By comparison, solar powered planes (e.g. HeliPlat) may have significantly less available payload power; this is a limitation similar to that experienced by satellites, and means that the achievable downlink RF power, and hence overall capacity, will be constrained. Indeed, solar powered planes have much in common with communication satellites, in terms of available power from the solar panels, payload weight and space available on the platform. Power will need to be used most efficiently, particularly through careful spot beam and antenna array design and power-efficient modulation and coding schemes.

Compared with a satellite, a HAP will require a higher proportion of the power to charge the batteries (fuel cells) because it must cope with long periods of darkness each night, the worst case being the shortest day (22nd December in the northern hemisphere). At higher latitudes both the variation in the angle of the sun relative to the solar panels between summer and winter, and the short winter days will have an additional significant effect. Fig. 12 shows the variation in incident solar power per square metre as a function of seasonal extreme, time of day, and latitude.

Advanced Technologies Group is suggesting the use of airships in which solar-powered technology is augmented with diesel engines that can also be used when station-keeping is a problem[15]. But the power budget is most acute for solar-powered plane technology, where the available area for the solar cells and the permissible mass for the fuel cells limit the power to the payload; this may critically determine the platform's viability.

6 The way forward

Although some of the goals for HAPs are a few years from realisation, there can be little doubt that aerial platforms will play an increasingly important role in the delivery of wireless services. A combination of 'technology push' from the providers of platforms and 'applications pull' from the inexorable demand for communications means that it is not so much a question of 'if' but 'when'.

Commercial aerial platform projects already underway include the HALO programme, and the PWI tethered aerostat project in Brazil. Solar-powered planes are developing rapidly, as is technology for airships. The big challenge is whether HAPs can provide the required grade-of-service, especially in the face of uncertain winds at their operating altitude. There is also the issue of long-term reliability, with manufacturers postulating on-station lifetimes of 5 years or more, which is far longer than those of any current aerial devices.

But these factors need to be balanced with the economic benefits of the service provided and the cost of through-life operation. High link availability may not be required of a single HAP in many scenarios, whether due to diversity techniques or because '99·99%' service is not demanded. And with the opportunity to bring HAPs back to ground for maintenance, the issue of long lifetime may be less critical.

One of the technical hurdles for the manufacturers of HAPs, whether solar-powered plane or airship, looks likely to be the performance of energy storage such as fuel cells, and there is considerable on-going work in this area. Although much can be learned from scale HAP prototypes, not all of the aerodynamic, structural and energy issues scale linearly, thus full-size HAP prototypes will need to be built and tested in order to convince users and investors of their commercial viability.

With the evident opportunities for enhanced communication services, as outlined in this paper, it is to be anticipated that we shall see significant developments in HAPs for communication service delivery over the next few years.

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