Airships As A Low Cost Alternative To Communication Satellites

by

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Abstract

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 of airships as low cost alternative for HAPs for delivery of future broadband wireless communications.

Need for High Altitude Communication Platform

Wireless solutions are becoming increasingly important, because 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

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provision for multimedia, which represents a convergence of high speed Internet, telephony, TV, video-on-demand and sound broadcasting.

Limitations of Satellites and Tower networking

Based on the studies carried out on the existing methods used for communication using satellites and tower networking, it was found that these methods have several limitations. Incase of Satellites, revenue generation only begins with launch of entire constellation (for e.g. Iridium has 66 satellites). It causes high latency (signal delay) and also there is a limited signal penetration through buildings. Moreover only one company can operate on the entire system and a technology set 3-4 years prior to deployment is required. Any upgrade requires the launch of an entire new constellation. A high infrastructure cost per subscriber, more than US $ 100 million per satellite [1] is involved. Even incase of tower networks, extensive lease and transmission systems are required. There is an inconsistent penetration of buildings in the line of sight in case of tower networking. We cannot shift capacities, and also the dead zones are quite common. Upgrades require a modification at each site and coordinated cutover. Further a complex and expensive installation and network management is needed. Network building requires literally hundreds of towers. Environmental concerns also pose severed restrictions on location of the towers.

Aerial Communication Platforms

A potential solution to the wireless delivery problem lies in aerial platforms, carrying communications relay payloads and operating in a quasi-stationary position at high altitudes. 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 (free space path loss), 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. These platforms may be manned or unmanned with autonomous operation coupled with remote control from the ground. Platforms under investigations include Airship, Airplane, unmanned aerial vehicle and tethered aerostat which reach up to 5 Km [5]. Airships use very large semi-rigid helium-filled containers. Another form of HAP is the unmanned solar-powered plane, which needs to fly against the wind, or in a roughly circular tight path. The most highly-developed such craft are those from AeroVironment in the USA, whose planned Helios plane has a wing-span of 75m; their Pathfinder and Centurion programmes have already demonstrated flight endurance trials at up to 25km altitude 80000ft [1]. HeliPlat is a solar-powered craft being developed under the auspices of Politecnico di Torino in Italy, as part of the HeliNet Project funded by the European Commission under a Framework V initiative [1].

Of most interest are craft designed to operate in the stratosphere at an altitude of typically between 17 and 22km, which are referred to as high-altitude platforms (HAPs). While the term HAP may not have a rigid definition, we take it to mean a solar-powered and unmanned aircraft, 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 worldwide, 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 [1].

Benefits of HAPs over other systems

HAPs are highly suitable for broadband wireless communications. They appear at a high elevation angle compared to terrestrial base stations, thereby mitigating the terrestrial propagation effects. With a visibility of around 200 Km at 5 Deg elevation, they can replace a large number of terrestrial base stations; and being considerably closer to the ground than satellites offer much lower path loss than satellites - better by ~ 34 dB for LEO satellites and ~ 66 dB for GEO satellites [5]. HAPs have been assigned frequency bands in 47/48 GHz and 28 GHz bands where at present spare spectrum is in plenty [5]. HAP telecommunication systems can be designed to respond dynamically to traffic demands; they are relatively low cost compared to satellites; they can be deployed incrementally and rapidly when necessary; the platforms and payload are upgradeable; and they are environmentally friendly using solar power, without need of launchers and eliminate the need of terrestrial masts. Typical cell size of HAPs range between 1-10 Km and the communication throughout can range between 25-155 Mb/s [5]. The coverage is regional, though it is possible to inter-link HAPs creating a national grid, or alternatively they can be connected to distant gateways via satellites. They have been proposed for broadband fixed wireless access (B-FWA), mobile communications as base stations, rural telephony, broadcasting, emergency/disaster applications, military communications, etc.

Airships for HAPS

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 (for e.g. the Breitling Orbiter10). Several high technology airship programs have been launched recently for e.g. Zeppelin NT [8] and Cargolifter [9] in Germany. Airships are thought to be the best alternative source of high altitude platforms for communication. A study is being carried out regarding as a means of high altitude platforms for communication.

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 [1].

Although the wind profile with altitude may vary considerably with latitude and with season, a form similar to that shown in Figure 1 will usually be obtained. This altitude (>16 km) is also above commercial air-traffic heights, which would otherwise prove a potentially prohibitive constraint.

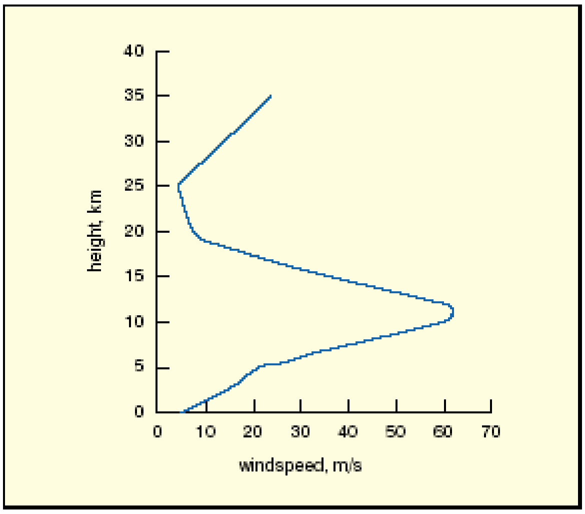

Figure 1. Typical Jet-Stream wind profile v/s altitude [1]

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. 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 400g/m^2 [1] and cover the upper surfaces of the airship. Additionally, during the day, power is stored in regenerative fuel cells, which provides all the power requirements at night. The overall long-term power balance of HAP is likely to be a critical factor, and the performance and ageing of the fuel cells determine the achievable mission duration. Within this height range, wind currents are low and commercial aviation is unaffected. This is a very cost effective alternative, which offers low technical risk and short development cycles. Airship services can be configured to satisfy the traffic requirements in metropolitan area. Further, the high elevation angles can substantially reduce the occurrence of dead zones and multi path fading.

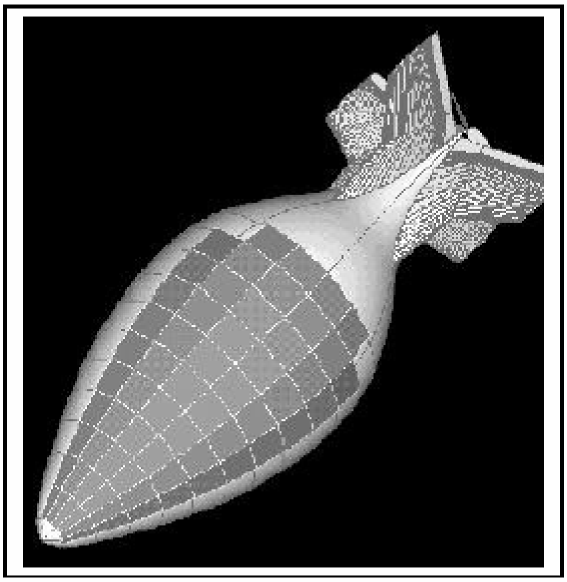

Figure 2. Solar cells placed on the HALE Airship platform envelope [5]

Benefits of Airships as HAPs

Airships have a very long flight endurance, which ensures continuous communications and surveillance coverage. Communication time delays will also be low due to comparatively lower altitudes than satellites. Technology upgrades during ground servicing is also possible. Airships can also serve in multiple applications as communication system such as in 3rdgeneration & 4th generation mobile services. A single base-station on the HAP with a wide-beam width 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 rollout covering a large region, relatively uncluttered propagation paths, and elimination of much ground-station installation.

HAPs do not require any launch vehicle, they can move under their own power throughout the world or remain stationary, and they can be brought down to earth, refurbished and re-deployed. Once a platform is in position, it can immediately begin delivering service to its service area without the need to deploy a global infrastructure or constellation of platforms to operate. HAPs can use conventional base station technology - the only difference being the antenna. The relatively low altitudes enable the HAPs systems to provide a higher frequency reuse and thus higher capacity than satellite systems. The low launching costs and the possibility to repair the platforms gateway could lead to less expensive wireless infrastructures per subscriber. Each platform can be retrieved, updated, and re-launched without service interruption. These platforms will be environmentally friendly, since solar technology and non-polluting fuel cells will power them. Studies carried out on the airships so far have shown that they require lower overall cost than satellite or ground systems, as given in Table 1. They have a larger payload weight and volume capability for multiple payloads, antennas, and optics.

The relatively low altitudes - compared to satellite systems - provide subscribers with short paths through the atmosphere and unobstructed line-of-sight to the platform. With small antennas and low power requirements, the HAPS systems are suited for a wide variety of fixed and portable user terminals to meet almost any service needed.

	Terrestrial Wireless Systems	Airship Technologies	Aircraft Technologies	Satellite Systems
Height over ground level	5-250 km	3-22 km	16-19 km	500-36000 km
Lifetime	Upto 15 years	Upto 5 years		Upto 15 yrs
Capacity	high	medium	medium	Medium
Orbit	Not applicable	Geostationary anywhere on the world	Geostationary anywhere on the world	Geostationary only on equatorial plane or non-geostationary
Coverage	Only land and shore possible	Land and sea possible	Land and sea possible	Land and sea possible
Estimated cost of infrastructure	varies	>$ 50 million	>$50 million	> $200 million
Fade margin	High	Medium	Medium	Low
Indoor reception	possible	?	?	Not possible
Remarks	- Maintenance possible - High number of transmitters necessary - Well known and proven technologies	- Maintenance & re-deployment possible - Unsolved power problems	- maintenance & re-deployment possible - unsolved power problems	- high launching costs - well known and proven technologies

Table-1 Comparison of the advantages and disadvantages of various wireless solutions [7]

Problems / Challenges faced by Airship HAPs

With the advantages mentioned, these have not been exploited commercially because the technology has yet to arrive. There are a number of open technical issues being actively pursued. A number of system issues are under investigation including - system architecture, frequency planning, network protocols, resource planning, etc. Propagation characteristics at 47/48 GHz are not well defined yet; modulation/coding techniques have to be optimized for such propagation conditions; 48 GHz antenna technology with multiple spot beams is under development [5]. Other issues include platform station-keeping, hand-off considerations even for fixed stations due to platform movement and payload power. HAPs have similar eclipse problem to satellite with regards to payload power due to the use of solar cells. Reliable platforms are yet to be developed.

The technological challenges faced today can be summarized as follows:

a) Stratospheric environment and thermal condition

Winds in the stratosphere are weak at approximately 20 km above sea level, and are believed to be weakest at 22 km where the atmospheric pressure is approximately 40 hPa in the middle latitudinal regions. Air density at this altitude is about 1/20 of that at sea level; therefore, the envelope needs to be large enough to yield necessary buoyancy. If the atmospheric temperature and the buoyant gas temperatures fluctuate drastically diurnally and annually, it will directly affect the buoyancy; buoyant gas expands or contracts with temperature fluctuations. If thermal variation is so large that the platform has to vent excessive helium gas at high temperature conditions, then the platform will lose buoyancy during sunset (lower temperatures) and possibly descend to the ground. In this context, thermal analysis and thermal limitation are important to design the vehicle and to determine the thresholds of structural capacity to cope with these thermal fluctuations and to circumvent such an unexpected operational abortion [2].

b) <u>Energy source for propulsion</u>

Solar energy can be harvested continuously in daytime in the relatively continuous ‘fair weather’ stratosphere. However, if nighttime becomes longer, as in the Polar Regions in winter, the platform requires ground-based wireless power transmission systems for continuous thrust powering due to the lack of solar energy. In this case, however, the platforms can be designed into much smaller sizes compared to solar-powered platforms.

c) <u>Energy storage</u>

Rapid progress in development of electrical automobile batteries lends itself to LTA secondary batteries for nocturnal propulsion, and there are good prospects that more energy efficient and lighter batteries can be developed in the very near future. [2]

d) <u>Propulsive efficiency</u>

Propulsive efficiency is one of the most important parameters affecting total vehicle weight [2]. Rigid airships in the past have had total volume drag coefficients of 0.022 - 0.023. It is assumed in this study that an optimized laminar flow body equipped with an aft propulsor achieves 0.020 as the total volume drag coefficient, considering recent research on the optimized laminar flow body.

e) <u>Aerodynamic design</u>

The airship is a pressurized balloon. Namely, the balloon skin is made of strong fabric that confines gas expansion and prevents buoyancy fluctuations from the buoyant gas temperature rise. The hull shape design was adopted from a study on minimum drag hull shape optimization [2]. The empennage sizes are determined by existing airship data. To get maximum propulsive efficiency, an aft propulsion three-bladed propeller is used. This example is feasible structurally as well as from the point of power-balances.

f) Ground handling, launch and recovery

Launch and recovery is perhaps the most difficult phase of airship flight [2], [4]. One important factor is the real estate required. This will depend on the size of the airship, its controllability and type of launch. The number of airships required to be moored or hangared at any one site would also affect the acreage. Many companies are planning large fleets but the build, launch and recoveries will need to be scheduled to optimize the ground area and manpower available. However, the wind profile during the year may force all launch and recovery operations to be conducted in a relatively short period. A restricted zone could be established around the launch site to reduce airspace management issues but this will still be an issue during transit and operation. Before starting discussions on ground handing methods, the vehicles' intrinsic characteristics as LTA stratospheric platforms are to be identified. Thereafter, requirements for ground handling have to be identified.

g) Hull structure

Challenges related to technology developments to actually construct gigantic pressurized thin fabric structures for these airship hulls are to be precisely identified and overcome, especially; those related to the technology of fabricating gas-tight ultra-light membrane pressurized structures and of constructing the tail wing assemblies as lightly as possible.

Current Developments Worldwide

The Wireless Innovation Systems Group of the Yokosuka Radio Communications Research Center in Japan [7] (refer figure 3). The airship has a semi-rigid hull of ellipsoidal shape with an overall length of nearly 200 m. It is composed of an air-pressurized hull for maintaining a fixed contour, and internal bags filled with the buoyant helium gas. Two air ballonets are installed inside the hull to keep the airship at a required attitude. For a load balance to the lifting force, catenary curtains are connected to a lower rigid keel, directly attached to the envelope. Propulsive propellers are mounted on both the stem and stern of the airship, and tail wings are installed on the rear end of the hull. A solar photovoltaic power subsystem of solar cells and regenerative fuel cells is provided to supply a day/night cycle of electricity for airship propulsion.

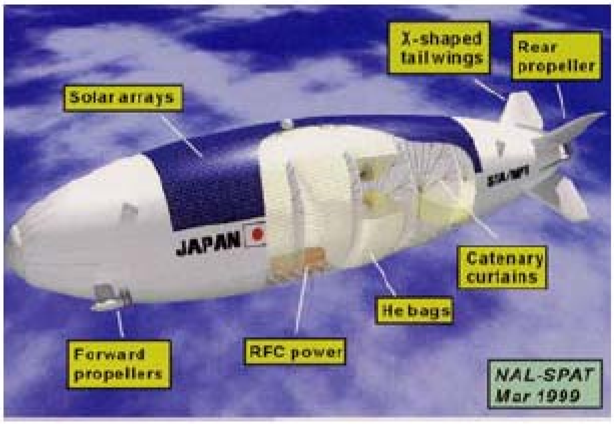

Figure 3: Artist’s rendering of Japanese Stratospheric Platform System [7]

The Airborne Relay Communications (ARC) System is the name of an airship platform planned by the US Company Platforms Wireless International [7]. The ARC system (refer figure 4) is designed to operate at lower altitudes, 3 to 10.5 km. Originally known as “Aerostats”, these airships were designed as airborne defense platforms for low-level radar use. Inspired by the dirigibles that monitor the border between the US and Mexico, Platforms Wireless International develops a system which shall provide fixed wireless broadband as well as mobile services to areas of 55 to 225 km diameter per system and servicing up to 1'500'000 subscribers (depending on system configuration and antenna projection power).

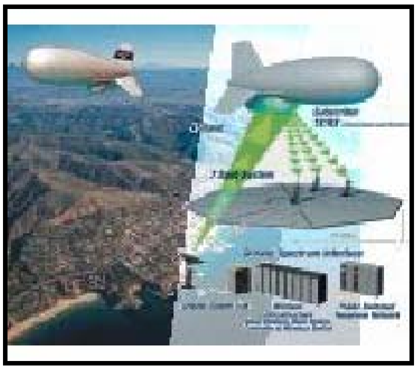

Figure 4: Artist's rendering of an ARC System [7]

An ARC airship is a 46 m long helium-filled balloon, which can carry almost 700 kg of payload. An airship configuration is designed with two supporting aircrafts, which will be deployed to ensure uninterrupted service coverage when severe weather conditions (winds in excess of 145 km/h) or monthly servicing require the temporary docking of the airship. ARC system is not using solar cells. Electricity is supplied to the payload via a 2.5 cm thick cable. It also incorporates a fiber-optic cable link that connects the airborne base stations to the rest of the network. A "no-fly zone" must also be created so other aircrafts do not fly into the airship or its cable.

StratSat (refer figure 5) is an airship system planned by the UK based company "Advanced Technology Group (ATG)" [7]. StratSat intends to offer a cost effective and safe solution for geo-stationary telecommunications payloads above large customer concentrations. With both civilian and military applications, the StratSat can be dispatched thousands of kilometers to station and kept there up to five years at a fraction of the cost of any alternative means. The airship in the stratosphere is well above conventional air traffic and presents no threat.

Figure 5. Artist's rendering of StratSat platform [7]

Key facts about ATG StratSat platform

- System capacity of 1000 billion call minutes a year (40 billion for Orange)

- At 60,000 feet the StratSat is out of range of any existing military missiles or the flight paths of any aircraft

- The full size StratSat is 200 m in length – equivalent to three 747's, while its width and height as 48 m.

- The volume of the StratSat is 269,000 cubic meters, and it can carry a payload of upto 1000 kg.

- At an altitude of 20 km, it can be kept for 5 years at a station and its maximum operating speed is 150 KTAS.

- The most advanced lightweight power and propulsion systems and materials that can withstand the greatest extremes of temperature and weather systems

- A high-density focused coverage over a 7,000 sq. mile area

- The airship can hold position to within 0.5 km of its target location.

A range of airships is being developed by Advanced Technologies Group, of Bedford, at one time in collaboration with SkyStation international of the USA15, who proposed an airship 150m in length supporting a communications payload of up to 800kg [7].

Sky Station (refer figure 6) is the name of an airship system planned by the US Company “Sky Station International” [7]. The number of platforms will depend on the demand (250 platforms are announced). The balloons will be covered with solar cells, giving energy to the electrical motors. The data rates foreseen for the fixed services are 2 Mbps for the uplink and 10 Mbps for the downlink. The data rates foreseen for the mobile services are 9.6 - 16 kbps for voice and 384 kbps for data. The cost of the entire project for a worldwide broadband infrastructure is estimated at $2.5 billion [7]. For a later phase, radio links inter-connecting the different platforms are planned.

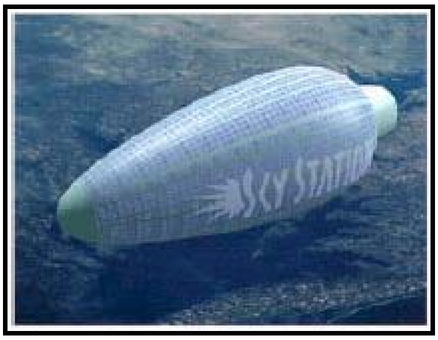

Figure 6. Artist’s rendering of a Sky Station platform [7]

HAP airships are also being proposed by Lindstrand Balloons. A novel design of HAP comprising several smaller airships joined together in an ‘Airworm’ configuration is being developed by The University of Stuttgart. This sausage-like formation aims to provide the lift while avoiding some of the structural and aerodynamic problems associated with very large airships.

Other companies engaged in the development of airships as HAP are: Lockheed Martin, USA, Alenia AEROSPAZIO, Spain, THALES and Astrium etc.

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