High Altitude Platform Concepts and Implementations

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Abstract—**The telecommunication systems used nowadays, though they are very well established, can still be improved to increase performance. Research on this topic is continuous in order to improve the already established systems, as well as finding new possible solutions. One of these new promising solutions are high altitude platforms (HAPs). This report will contain a summary of findings from various articles on the subject, where the main parts of the report will be the HAPs concept and its properties compared to currently used systems, different technical implementations and projects associated with these techniques, use cases and system capacities. The conclusion in the report is that HAPs do have promising attributes, but since the interest in the technique has been low, many early projects have been shut down due to insufficient funds. The interest in HAPs has grown in later years, probably due to the development of more efficient batteries and solar cells, which are often needed in HAPs solutions to make it self-sufficient on energy. Now there are many projects under development that show promising results. Although HAPs did have a rough start, it is expected that its impact will grow in the near future.**

I. Introduction

The interest and need for high speed wireless communication is constantly growing, especially now with the shift into a more connected world where everything from cross roads to smartphones and cars is connected. To cope with the growing demand there is constant research to improve existing solutions and to find new solutions for increasing the performance of telecommunication networks.

This report presents a lesser known solution for telecommunication services, the high altitude platform (HAP). A HAP is a quasi-stationary platform, which operates above the commercial air traffic, but still within the atmosphere [1]. There has been research on this solution for a while, however it has stayed rather unknown in the public eye. This report will highlight HAPs as an interesting alternative solution to terrestrial- and satellite-systems. In the report the following questions are going to be answered:

- What is a HAP?
- What can HAPs be used for?
- What are the expectations on HAPs, in terms of capacity?
- What is the current state of HAP development.

The answers to these questions will be gathered from various articles on the topic. The focus of the report are HAPs, however both the terrestrial- and satellite-system will be presented briefly presented. The objective behind this is to give a better understanding of the advantages and disadvantages HAPs have in comparison to these more established solutions. For satellite systems we are presenting two types of satellites, geostationary earth orbit (GEO) and low earth orbit (LEO). There also exists a third one, the medium earth orbit (MEO) that could have been included, but since it has similar properties as LEO satellites it was skipped in order to avoid redundancies.

II. Current telecommunication systems

As of today telecommunication networks rely on two very different classes of systems that collaborate to give stable transmissions in both rural areas, where users can be far apart, and urban areas, where the network needs to support the high density of users. These two classes are terrestrial network systems and satellite systems. They have very different properties. Both the systems are used for individual purposes but since their properties differ, there are use cases where it is beneficial to use them together.

Wireless terrestrial networks are land based systems, which means that the base stations are built on the earths surface. These base stations are often built in specific spots and together they build a mesh of cells in order to fully cover an area. Since the base stations are placed not far off the ground, the signals are very often not in line of sight of the user equipment (UE). This means the signal suffers from attenuation and shadowing by nearby obstacles. Thereby, a base station in a wireless terrestrial network does have relative short coverage area but at the same time low latency. Terrestrial systems might also be affected by outages in cases of a catastrophe like earthquakes, tsunamis or power failures. [2]

The other class of systems, satellite networks, use base stations in space. The satellite will for the most part stay in orbit by itself since its speed is balancing out the gravitational pull. However, small forces can make the satellite go out of orbit. In order to keep its position, a satellite is equipped with thrusters and limited fuel load. When a satellite runs out of fuel, it will either drift into space or burn up in the earths atmosphere. A satellites lifetime is often based on the amount of fuel it received during launch. Satellites are in most cases not recovered after their launch, and it is very hard to upgrade them while in orbit. Therefore, in order not to break and stay functional, a satellite needs to have all kinds of extra protection and have specially made hardware. This, and many other factors makes development of satellites very expensive. In the following sections, two different types of satellites are presented. These are the GEO and the LEO satellites. [2]

Geostationary earth orbit (GEO) satellites are located at a height of approximately 36,500 km above the ground [2]. This latitude is special because it gives the satellite an orbit time of 24 hours. By deploying satellites at this latitude it gives the satellite the desirable property of staying fixed relative to a point on earth, and can continuously provide service to the same area. Because of their elevation they have a line of sight to large parts of the earths surface. Since they are stationary, one is needed in order to have a functioning system and with three GEO satellites most of earths surface can be covered [2]. The drawbacks of GEO satellites however also comes from the height. The long distance the signal has to travel results in long transmission delay for the connection and high attenuation [2]. The transmission delay makes it troublesome to use GEO satellites for speech. It could also cause difficulties with some data protocols [3]. It also limits the use of GEO for high speed internet transmission [2].

Another type of satellites are the low earth orbit (LEO) satellites. They are located at around 1000km above the ground. This latitude, compared with GEO satellites, results in less coverage area, lower latency and lower signal attenuation. LEO satellites are cheaper to produce than GEO satellites, however they are more complicated to deploy. LEO satellites do not come with the stationary property that GEO satellites have. In order to have a fully functional system there are more satellites needed (12-66 satellites). The satellites need to communicate with each other in order to handle handovers between them, which comes with a handover delay. Because of the lower latency, LEO satellites are more appropriate to use than GEO satellites for various network services. [2]

III. The HAPs concept

Both the terrestrial and the satellite systems have their advantages and disadvantages. The benefit of the terrestrial systems is their low latency and their flexibility, where deployment and upgrades can be done easily. The satellite systems on the other hand have the advantage of large coverage area. A relatively new solution that tries to combine the beneficial properties of both solutions is the HAP.

A HAP is defined by the International Telecommunication Union (ITU) as ”a station on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth” [4]. In practice this often means either an aircraft, balloon or airplane that is staying in one position and is equipped with receivers and transmitters in order to work as a base station. The idea is similar to GEO satellites, but at less altitude, therefore with less latency and less signal attenuation.

Unlike satellites, a HAP does not orbit and needs to manage gravitational pull in a different way as well as wind and other environmental impacts. It is desirable to place them at an altitude with low wind speed in order to make position-keeping achievable and as easy as possible. As shown by figure 1, the altitudes between 18 to 25 km have on average less wind speed than other heights and make a good height range for HAPs [1]. The altitude range is also above the operational height of commercial aircrafts [1], which would have caused problems otherwise, and the altitude lies above the troposphere, where most weather conditions take place [5].

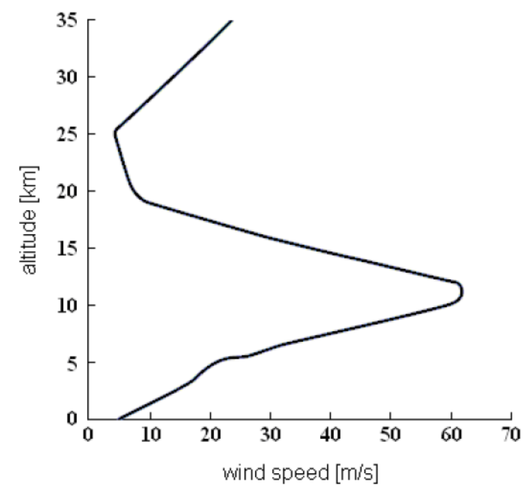

Fig. 1. Wind speeds with respect to the altitude. Source [1]

In order for the HAP to provide services over longer time periods, which is the goal in many cases, which include keeping the platform quasi-stationary, the HAP needs to be self-sufficient on electrical energy. A HAP also requires electric energy for the payload it carries, like antennas and electronics. A common solution is to have solar panels generate all electricity needed. In order for the HAP to stay stationary over longer periods, it is required to store all electricity needed at nighttime during the day, as well as manage to function normally at the same time. This is one of the big issues the HAP concepts are facing. [2]

Another consideration that comes to the placement of a HAP unit is that different latitudes of the earth get different amounts of sun time depending on the time of the year. Both GEO and LEO satellites experience very little sun eclipse over a year (GEO 1.2 hours only twice/year), whereas a HAP, depending on the placement, could be experiencing more than 12 hours sun eclipse per day (24 hours if it is placed at one of the poles during their winters) [2]. Therefore HAPs need larger and heavier energy storage systems than satellites do. One possible solution to overcome the shortage of energy delivered by the sun would be the use of microwaves sent from the earth, which are received by rectifier antennas [2].

Some additional information on HAPs is that ITU have designated frequency band spectra to HAPs, and is planning on designating more spectrum to HAPs in the future [4]. In

2020 a cooperation called the HAPS alliance was formed. The cooperation consists of 12 companies from around the world, which are major stakeholders in the telecom and aviation industry. The idea behind this cooperation is to advocate for HAPs and start developing standards for interoperability of HAP networks [6].

For now there is active research and development on two different types of HAP systems, aerostats (balloons and airships) and aerodynes (aeroplanes). There is also a differentiation between manned vs. unmanned aerial vehicles (UAV) when talking about different HAP solutions. Many HAP projects have started over the past 20 years. Most of these have been discontinued, but some projects have reached a more advanced stage of development with significant financial resources. In the next sections, the HAPs types are presented. [3]

A. Aeroplanes

The lifting force of an aeroplane comes from the aerodynamic force on the wings that is created when the plane is moving forward. For the HAP plane not to fall down it therefore always needs to be in motion. To still cover a specified area, this type of HAP often flies in circles. The most promising HAP plane solutions are unmanned planes flying on either hydrogen power or solar power. The idea for these unmanned planes is that they should be deployed over large time periods and only be taken down when they need to be upgraded or repaired. This of course means that the HAP has to be self-supporting on electric power. The advantages of this solution is the fast and easy platform deployment and the ability to move from one service area to another. The main challenge with this solution is likely to be the power balance. [3]

The other type of HAP plane is the manned plane. In this solution a single HAP can only be deployed for a few hours. This solution is mainly used to provide emergency connections for areas afflicted with disaster. The manned HAP could also be a solution for short term growth of telecommunication traffic in an area during e.g sport events, festivals or other big events. [3]

1) Current developments: In this section four different projects are going to be presented. In all these projects, the solution consists of unmanned aeroplanes, supposed to be deployed over longer time periods.

a) Zephyr: This plane started to be developed in 2001 by QinetiQ. There have been some different versions of the Zephyr, where version S is the prominent one. Zephyr S was the first operational HAP to be contracted. It has a wingspan of 25 meters and a weight of less than 75 kilo. On the 11th of July 2018 a prototype of Zephyr S flew for record breaking 25 days, 23 hours and 57 minutes without re-fuelling. Besides that it also flew in excess of 74000 feet and showed the capability to remain in the stratosphere overnight. In July 2018 the production of the Zephyr started. [7]

b) Solara: This project owned by Google presents the Solara 50 UAV. The prototype of the Solara 50 was in May 2015 destroyed during its first test flight. It had a wingspan of 50 m with the weight of 159 kg and payload of 32 kg. It was expected that the Solara 50 could be capable of flying at an altitude of 20 km for up to 5 years. Since then Google has announced that they will continue with the project but it is unclear of the current state of the project. [7]

c) Aquila: The Aquila UAV is a project being developed by Facebook. It has a wing span of 42 m and a total weight of 400 kg. The four electric motors will be supplied with power from solar cells at day and rechargeable batteries at night. The deployment altitude will be between 18 to 27 km and the work time will be for 3 months. To achieve high-speed communication network, it will use laser connection. In 2018 Facebook had successfully performed two full scale test flights. In February 2016, Facebook had the intention of deploying the solution in India, however it was never achieved. In 2018 Facebook instead announced that project Aquila would be permanently grounded but the company is still doing research in the HAP-field. [7]

d) Hawk30: In 2018 the company HAPSMobile that is a joint venture of SoftBank and Aerovironment started the development of Hawk30. The aeroplane has a wingspan of 78 m with 10 electric-driven propellers and it is designed to fly at a speed of more then 100 km/h [8]. As of today the Hawk30 has successfully performed two flight tests [9].

B. Balloons and Airships

Balloons and airships have several properties in common. Both are aerostats, which means they lifted through gases, which are lighter than air. The usual choices are Hydrogen or Helium [7]. Due to the low air pressure at the intended heights of HAPs, a larger envelope with more buoyant gas is needed. This means that there are more drag forces applied to the aerostat that have to be taken into account [10]. Airships and balloons have two bags inside the envelope. One is filled with the buoyant gas, and the other one with atmospheric gas. The more volume that is taken by the buoyant gas, the more height the aerostat gains [10]. These concepts rely on solar energy as a power supply. Fuel cells or batteries are loaded during the daytime in order to supply the platforms during the night [7].

On the other hand there are various important differences between balloons and airships that need to be mentioned. The most important ones are the steering and the propulsion. A balloon moves up or down until it reaches an area with a favourable wind direction. In case there is wind, when the balloon should keep its position, it will drift and it has to get to a height where the wind blows the other way[11]. An airship uses propellers to gain thrust and to move in the desired direction [12].

1) Current developments: The two most promising projects are Loon, which uses a balloon design, and the airship Stratobus.

a) Loon: This project is owned by Alphabet Incorporated. It is meant to deliver long term evolution (LTE) connection to areas with insufficient or no terrestrial coverage, for instance in deserts, after catastrophes or at big events that need more capacity. One balloon consists of antennas, solar panels, a flight capsule with electronics and batteries inside and a parachute. When a balloon is launched it can stay up for over 100 days. The balloons navigate and build the network autonomously. The on board processors run predictive wind models to find the heights with favourable wind directions. Operators on the ground keep track of the aerostats via GPS. Data is sent from the ground station to the closest balloon, and then it is forwarded through the Mesh network in the sky to the end user on the ground, who needs nothing more than a LTE phone [13]. Since 2018 Alphabet Incorporated has been working with Telekom Kenya to improve 4G connectivity in Kenya. Due to the Covid-19 crisis the government in Kenya speeded up the approval process and allowed deployment of loon balloons in March 2020 [14]. The balloons are able to deliver data rates up to 10 Mbit/s for communication between the balloons and to the ground [15]. According to [16] there are currently 2 balloons in the airspace over Kenya.

b) Stratobus: The objectives of this design, made by Thales Alenia Space, are more various compared to Loon. Not only is it intended for telecommunication, but also for navigation and observation purposes, both military and civil. In its standard configuration it can carry 250 kg with a power rating of 5 kW. At the equator it can bear 450kg with a rating of 8 kW. Placed between the tropics with windspeeds less than 90 km/h it is possible to achieve an operational duration of 5 years, and where the airship will be brought down once a year for maintenance. The position-keeping and re positioning is done autonomously by the use of 4 engines. The energy supply system consists of solar cells for daytime operation and charging of the fuel cells that are used during the night. By rotating itself in a way that the solar cells are pointed directly towards the sun it is possible to optimize the energy obtained by the cells. The first prototype test flights should take place at end of 2020 or 2021 [17].

IV. Use cases

HAPs can deliver broadband wireless connection, especially at remote locations or rural areas which are not sufficiently supplied with this service. Furthermore they can be used as backhaul links, where they connect the edge of a network with the backbone of the network [10].

In case of a natural disaster like earthquakes, hurricanes and floods, which destroys the communication infrastructure, HAPs are highly applicable, due to their fast deployment [1] . Another application that can benefit from HAPs is broadcasting. HAPs are better than satellites, because they need less power, but the same applies to terrestrial radio towers. Research carried out by SkyTower showed that 1W transmit power from a HAP has the same result as 1000 Watts from a comparable terrestrial system [18].

Another field of application could be remote sensing. HAPs would monitor the weather, gather atmospheric data, detect hurricanes, measure the pollution in certain areas [2]. Currently satellites are used for some of these use cases, but HAPs have a special advantage here compared to satellites that do not stay at a fixed relative position to earth. Medium Earth Orbit (MEO) and LEO are always in motion, therefore it is difficult to observe a certain area or object on the ground [7].

Not only can natural processes be monitored, but in a military sense HAPs are also applicable for intelligence, surveillance and reconaissance missions, like missile warning systems. In the civilian domain they could be used for traffic control on land, sea and air [2]. The accuracy of GPS can be improved with differential correction through HAPs [1]. This works by adding the information from an object with a well known position (in this situation the HAP postition) to the position information gathered from the GPS satellites [19].

V. System capacity

One HAP can replace several terrestrial base stations. According to [2] the coverage of a HAP can be up to a diameter of 500 km, compared with 30 km of a base station on earth. In urban areas it is even less than 30 km. By using different antenna beams, one HAP can build the cellular structure from the terrestrial system with a diameter of 1 to 10 km per cell [3]. Due to this more centralized approach of a base station 20km above the ground it is much easier to dynamically reassign resources by shaping the cells through the beam widths. HAPs have significantly less dispersion loss than satellites of approximately 50/30 dB compared with GEO satellites (36000 km height) and LEO satellites (700 km) satellites respectively [2]. Furthermore, GEO satellites have a lower limit to their antenna beam diameter, which could be a problem for Internet access, if there are too many users in the vicinity of one beam. The satellite has to use the same frequency resources for a beam with at least 400km diameter [3]. Additionally, the delay due to the distance is considerably smaller for HAPs than for GEO satellites. The round trip time is 250 ms for GEO satellites, 0.3 ms for LEO satellites and 0.26 ms for HAPs [10]. The latency of LEO satellites is not significantly worse than the one of HAPs. However they face other drawbacks instead. LEO satellites are not stationary. Therefore more of them are needed to cover a certain area in connection with handover algorithms. HAPs are by far cheaper than satellites, but more expensive than the terrestrial infrastructure, although there are no concrete numbers for the terrestrial system [2] [3]. As mentioned previously Loon can deliver 10 Mbit/s [15]. According to [2] a HAP should be able to deliver 10-1000 Mbit/s.

VI. Discussion and Conclusion

One important aspect of HAPs is that depending on the placement of the HAP it will receive different amounts of sun time. For the equator it will have roughly even distribution of daytime and nighttime. This will of course determine where you are able to set up these systems in the future and this will be dependant on how energy efficient the solutions will be, especially for the solutions that are supposed to be deployed over several years at one spot. This should be a concern for HAP developers, since this drawback will create limits for how HAPs could be deployed around the world.

It is hard to develop a functioning HAP since it needs to be self sufficient on electric energy. But it is still easier to do now then in the past. The interest in more environmentally friendly solutions has lead to more efficiency in both batteries and solar cells. It is not difficult to see that the lack of interest in HAPs in the past could come from this. It was a difficult problem to solve and it was not really needed anyway, the terrestrial and satellite system were sufficient. However, today with better techniques, companies found ways to solve these issues, and have started putting more resources into making HAPs a reality. One revolution that has changed daily life since the second half of the last century is Internet itself. Now most people in developed countries are reliant on its services, and it has helped making massive progress in societies. One interesting thing is the new visions of some companies that want everyone to be able to have access. For this vision HAPs are a really good choice and this could be another reason for the increased interest.

One conclusion that can be drawn from all of this is that the HAPs do have a good combination of advantages that makes it perfect to use in some cases where both the terrestrial system and satellite systems are insufficient, for example natural disasters, coverage of larger rural areas. It can also be incorporated into the existing telecommunication network and contribute with high speed wireless communication. With this said, it can be expect to see more from HAPs in the future.

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