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Study for Leichtwerk AG

The role of HAPS for broadband coverage in rural areas

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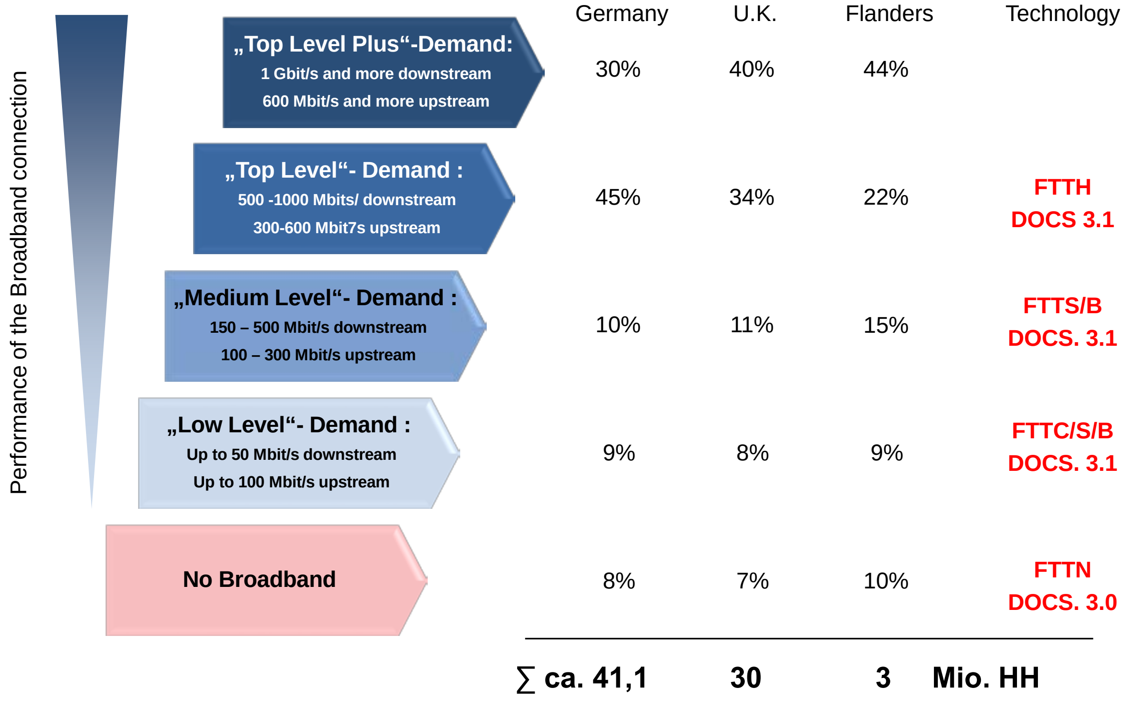
Abbreviations:

CO_2	Carbondioxide
DOCS.	Data over Cable Service Interface Specification (full abbreviation: DOCSIS)
EU	European Union
FTTB	Fibre to the Building
FTTC	Fibre to the Curb/Cabinet
FTTH	Fibre to the Home
FTTS	Fibre to the Street
FWA	Fixed Wireless Access
Gbit/s	Gigabit per Second
GEO	Geostationary Earth Orbit
HAPS	High Altitude Platform Systems
HH	Households
Km	Kilometre
LEO	Low Earth Orbit
Mbit/s	Megabit per Second
MEO	Medium Earth Orbit
Ms	Millisecond
NFV	Network Function Virtualisation
OAM	Operation, Administration and Management
RAN	Radio Access Network
SDN	Software Defined Networking
U.K.	United Kingdom
VDSL	Very high speed Digital Subscriber Line

1 Initial situation

Demand for broadband telecommunications connections is rising continuously. Studies by WIK forecast a demand of more than one Gbit/s downstream and more than 600 Mbit/s upstream for more than 30% of German households as early as 2025[1]. Bandwidth demand is being driven on the one hand by the parallel use of different applications and on the other by the fact that the applications themselves are placing increasingly high demands on the performance of the underlying infrastructures. These bandwidths can no longer be provided with the traditional copper access network, even with the help of high-quality transmission technologies such as VDSL super vectoring or G.fast. This requires fiber-optic networks or cable TV networks with DOCSIS 4.0, which in turn require optical fibers right up to the front of the house.

Figure 1-1: Forecast of bandwidth demand 2025



Source: WIK.

The roll-out of fiber-optic networks in sparsely populated areas with long line lengths per household to be connected is considerably more expensive than in densely populated

1 For this forecast, households were differentiated by size and user type, and parallel use of the connection and several applications per person by up to 4 people was assumed. The model is based on the assumption that bandwidth availability is not a bottleneck. Cf. Strube Martins, S.; Wernick, C. (2020): Regional differences in residential demand for very high bandwidth broadband internet in 2025, in: Telecommunications Policy, Volume 45, Issue 1, February 2021.

areas[2]. For sparsely populated areas in particular, efficient and inexpensive alternative communication technologies are therefore being sought that support sufficient bandwidths. These must also satisfy other qualitative aspects with regard to the propagation delay, the fluctuations in propagation delay (jitter) and the data loss rate (packet loss ratio). The lower these values, the better the quality in this respect.

Therefore, connection technologies that have no or only low distance-dependent deployment costs are primarily considered. Radio-based solutions are an obvious choice here. On the one hand, existing mobile communications antennas or those still to be expanded can be used for stationary applications via so-called fixed wireless access solutions (FWA); on the other hand, flying antennas can cover larger areas from air than is possible with ground based mobile communications. They are therefore particularly suitable for sparsely populated areas. Such approaches are the focus of this paper.

2 The costs generally ranges from < 500 €/household to > 125,000 €/household. Cf. as an example for the area of the German-speaking Community in East Belgium Wernick, C.et al. (2020): Ansätze und Kosten einer flächendeckenden Glasfasererschließung im Gebiet der Deutschsprachigen Gemeinschaft in Belgien, study commissioned by the Ministry of the German-speaking Community, Bad Honnef, 29.04.2020, available electronically at: https://www.wik.org/fileadmin/Studien/2020/Glasfasererschliessung_in_der_DG_Belgien.pdf.

2 Radio-based broadband coverage using flying antennas

By flying antennas, we mean telecommunications antennas that cover a larger area from a height of several kilometers, generally unaffected by shadowing[3]. Such systems based on satellites have been around for several decades. They have undergone constant development, partly due to considerable improvements in the performance of transmission systems, coding techniques and antennas, which can focus their power on specific areas that can be separated from one another by means of so-called beams (radio lobes).

Among the satellite solutions, a distinction can be made between GEO (geostationary earth orbit), MEO (medium earth orbit) and LEO (low earth orbit). GEO satellites are fixed at an altitude of 36,000 km above the equator. MEO satellites, which fly at lower altitudes (about 10,000 km), orbit the Earth and are not geostationary. They require a few partner MEO satellites to provide permanent coverage to an area[4]. For LEO satellites orbiting the Earth in ellipsoidal orbits, the altitude may vary between about 300 and 2,000 km during an orbit due to the trajectory. Before a LEO disappears behind the horizon during its orbit around the Earth, another LEO must appear to take over the radio link and thus avoid an interruption. Solutions using LEOs therefore always require a larger group of similar satellites operating in parallel and in coordination with each other[5]. Moreover, LEOs always cover only a relatively narrow strip because of their low altitude.

A qualitative problem of communication via satellites is the signal propagation time, which is dominated by the distance to be bridged. The signal transmission itself takes place at the speed of light, the upper limit of what is physically possible. Electronic signal processing in the satellite itself on the other hand, now plays a rather negligible role. The low-flying LEOs do have a significantly shorter signal propagation time. The propagation time fluctuates however because the satellite's distance from the subscriber changes constantly during the flyby, first shortening it and then lengthening it again. Additional fluctuations result from the ellipsoidal trajectory as well as from the signal transfer when changing from one satellite to the next satellite replacing it. Transit time fluctuations are thus inherent in the system. Buffers can compensate for these, but add a constant delay.

HAPS (High Altitude Platform Stations) are flying objects flying in the stratosphere (about 20 km), drones based on the design principle of gliders, which are kept geostationary and cover an area with a diameter of 100 - 200 km with their antennas.

3 Shading in narrow development, e.g. by street canyons, can occur but is irrelevant in sparsely populated areas.
4 A typical MEO system is the European Galileo navigation system with about 30 satellites at a flight altitude of 23,222 km.
5 Leo solutions like the European OneWeb project use approximately 650 satellites; ELON Musk’s Starlink project aims for more than 1,600 satellites covering the whole populated continents of the earth.

Due to the short distances between the ground and the antenna, in contrast to satellites, quasi-terrestrial transit times result in comparison with all other solutions. The HAPS can be powered either by solar cells (as with satellites) or by hydrogen fuel cells. The latter allows more energy to be harvested, but requires the drones to return to Earth every week or so to be refuelled. To enable continued operation, each drone is replaced by another at the same position. This approach has the great advantage that the most powerful mobile radio technology can be used on the HAPS virtually as standard, which is capable of communicating with terrestrial mobile radio devices in the classic 4G/5G protocol[6]. In contrast to satellites, this also enables maintenance and upgrade work to be carried out without any problems.

Table 2-1: Terrestrial telecommunications via satellites and HAPS

Carrier Type	Altitude	Signal Propagation Time 1 way Up/Down	Carrier Number*	Antenna Coverage
GEO	36,000	500-700	1	Continents
MEO	10,000	125-250	1	Subcontinents
LEO	300-2,000	20-50 varying	40-1680	Ellipsoid strip (Countries)
HAPS	12-20	<5	80	Regional circles

* at least for coverage of Germany

Source: WIK 2021.

For good voice communication, the propagation time of the signals end - end should not exceed 100 ms. It must be taken into account that the solution approaches discussed here only cover the solution of one network access. In practice, the distance to be covered may be considerably longer, since connections have to be routed and terminated in additional networks. This is particularly relevant for international connections or, in extreme cases, when additional flying antennas are involved.

This underscores the fact that GEO and MEO solutions are hardly an option for the broad end-user market, but rather as a compromise in cases where terrestrial solutions would be too expensive. Even solutions using LEOs have signal propagation times significantly higher than terrestrial solutions - only HAPS comes very close to these and can be integrated into e.g. mobile radio solutions.

6 Kickert, R. (2021): High Altitude Platform Stations (HAPS), Luft- und Raumfahrt, 2/2021; see also https://haps-broadband.org.

3 Usage-related aspects

The capacity of a flying solution is determined on the one hand by the footprint covered by the antenna. This describes the space (cell) illuminated by the antenna. The users located there can be addressed. However, they share the capacity of the radio channel between the terminal and the flying antenna[7]. The capacity available per user thus decreases proportionally with the number of users supplied per cell.

This fact makes it clear that high-flying antennas cannot be targeted at the mass market for individual communications, but represent special solutions for sparsely populated areas or are aimed at expeditions or seafaring. The more broadband the communication requirements become, the scarcer the capacities available to everyone. Although beamforming can be used to divide the frequency space into subspaces if necessary so that fewer transmission collisions occur, the frequency space remains limited.

The smaller the footprint of the antenna with basically constant capacity, the more capacity it is available to individual customers, or the more customers can be served (with constant capacity). Projections for LEO solutions for individual communications estimate the addressable market in Germany at < 200,000 customers due to the required capacities.

The satellite-related service requires sensitive receiving equipment. For GEO and MEO these are the well-known receiving dishes with bulky handiness up to stationary solutions. The antennas need to be aligned or tracked. For LEOs, tracking is not absolutely necessary and would also be very costly, especially when changing satellites. Here, special handsets with omnidirectional antennas[8] are usually available for the various systems, but they have nothing in common with the familiar cell phones. HAPS, on the other hand, work with the normal mobile phone terminals and can thus be integrated into the everyday usage environment conveniently and at low cost for the end customer.

Like cellular networks, HAPS-based telecommunications services can be used without restriction on a mobile basis or geostationary as fixed wireless access (FWA). GEO and MEO allow nomadic use at best, combined with ground antenna realignment. LEOs are generally mobile, depending on the provider.

Telecommunications technology becomes obsolete relatively quickly. New transmission methods and coding technologies regularly appear on the market. Antenna technology and electronic systems become more powerful, and software functionality improves. As a result, software upgrades are usually required, some of which can only be performed

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7 This is determined by the width of the usable frequency band, the signal coding used and the performance (capacity) of the flying electronics as well as their power requirements.

8 Starlink has flat antennas that automatically track instead of handsets.

on-site at the system. While there are no restrictions in this respect for HAPS in the ground phase, this is not possible for satellite-based systems.

Since HAPS can be equipped with mobile radio technology, they are able to contribute to the fulfillment of coverage requirements of mobile operators in sparsely populated areas. In the best-case scenario, this could result in nationwide cellular coverage without the need for subsidies. However, this presupposes that the HAPS can be launched in good time. HAPS can also be deployed more selectively, i.e., where they can exploit their advantages, and do not have to cover entire regions or states with possible associated coverage losses. This makes it possible to achieve targeted economic optimization.

4 Utilization aspects of the Earth's orbit

The satellite-based solutions require either a geostationary position in orbit (GEO) or even entire orbits (MEO), quasi as a wide strip or as a shell, which may remain open only at the poles (LEO). It must also be monitored to ensure that there are no collisions between the orbiting satellites. HAPS, on the other hand, each require a fixed position in the national stratosphere and do not move from the spot there. So while satellites require coordination within the international, and possibly the global sphere, HAPS are subject to national and the EU possibly European, airspace coordination.

All satellite-related solutions operate on frequencies reserved specifically for satellite communications. While geostationary satellites require frequency rights only in their footprint, MEOs and LEOs are in principle active around the globe and accordingly block the frequency space globally. HAPS share the regular spectrum of mobile communications, which is typically managed nationally.

The space debris from the past 50 years of space travel already puts a considerable strain on the Earth's orbit and also repeatedly causes damage through collisions. By far not all junk sinks to Earth and burns up in the atmosphere. Some sinks to Earth, but does not burn up completely. The resulting problems are increasingly aggravated with the additional use of satellite-based solutions. HAPS, on the other hand, regularly return to their point of origin and are serviced there until they are relaunched.

5 Technological outlook on trends in mobile communications

In mobile communications, there are lively development trends in terms of capacity, quality and application areas. The following are just a few examples

- network sharing
- Software Defined Networking, Network Function Virtualization (SDN/NFV) with its main manifestation in network slicing
- OPEN RAN (Open Radio Access Network).

A HAPS-based solution can participate directly in these developments by participating in the innovation pool of solutions for the mobile radio mass market. Such solutions are theoretically conceivable for satellite-based systems, but because they are special systems - in principle individual developments or developments in small numbers - they are expensive to implement and can only be realized to the extent based on software upgrades. The hardware of a satellite cannot simply be exchanged.

In the case of HAPS, these approaches provide options for shared use by other network operators who share and fund the flying platform.

6 Multi-operator environment

In principle, HAPS can be used in parallel by several telecommunications providers in a similar way to mobile radio towers. However, the energy supply and possibly the space capacities on board have a limiting effect here. Under certain circumstances, the HAPS would have to be replaced at much shorter intervals. Approaches that envisage the joint use of the installed electronic platform therefore appear to be more efficient.

In this sense, network sharing solutions are conceivable via roaming, in which other network operators share the platform of the HAPS and its transmitter. If necessary, the frequency space could also be combined and shared. Such solutions are already technically implemented in mobile networks today.

In the implementation of network slicing in mobile communications, the capacitive space is divided into capacity bands (layers) to which qualitatively different usage classes can be assigned and/or which are left to different users in the wholesale or retail business and jointly optimized in terms of capacity. Such solutions are currently being implemented or are already available in the mobile network.

OPEN RAN, on the other hand, is still a dream of the future. In principle, so-called white boxes are standardized as general transmission systems which, combined with network slicing, are controlled by several operators from their individual network control systems (OAM, Operation, Administration and Management). Assuming that the flying antenna with its transmission system in the HAPS represents a so-called white box, several operators could control its use from their own network on an operator-specific basis within the framework of coordinated use of the total capacity of the white box. This presupposes that the flying white box has sufficiently standardized interfaces and that the operators can operate them. In order to reach sufficient implementation maturity, this vision still needs a lot of standardization work in the context of Open RAN.

7 Conclusion

In summary, the solution of using HAPS as a platform for flying antennas offers significant advantages over satellite-based solutions in terms of capacity and quality. Their selective use offers the option of economic optimization. When used as cellular base stations, they can easily be integrated into existing and future cellular infrastructures and can use their fixed and mobile terminals without the need for separate equipment, adapters or even antennas. In principle, they are also suitable for use by several network operators, so that they could be deployed very cost-effectively, especially in sparsely populated areas.

The energy supply from hydrogen and fuel cells is CO_2-neutral. Because HAPS always return to Earth for refueling, they do not pollute orbit with space debris. During their ground stays, they can be adapted to technical advances in mobile communications at any time.

Finally, HAPS are able to assist in meeting coverage requirements of rural cellular frequency subscribers and may also be able to reduce or even eliminate the need for government funding to cover white spots not covered by coverage requirements. However, this requires that they be operational in a timely manner for these purposes.