High-altitude platforms and satellite constellations

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Introduction

High-altitude platforms and constellations of satellites are intended to provide an infrastructure for fixed or mobile wideband access in zones where mobile terrestrial networks are not economically profitable. This concerns more than a third of the planet's inhabitants. High-altitude platforms can be rolled out, one by one, at a rapid pace depending on each country's needs, whereas a constellation of satellites, once all the satellites have been launched, could provide the whole planet with an available infrastructure.[1]

Twenty years ago, we could imagine that, thanks to technological progress, such systems would soon be in operation. For this purpose, many requests for radio-frequency spectrum bands were addressed to the world radiocommunication conferences (WRC) at the International Telecommunication Union (ITU). Satisfying these requests was, in both cases, a technical and regulatory conundrum. How to authorize such systems to have access to bandwidths without risking interference with the other services (terrestrial or satellite) already allocated to these bandwidths? Following laborious negotiations, WRC-97 found a solution; and subsequent WRCs followed up on it and made more of the spectrum available for these new services.

Although the crisis in the early years of the millennium halted the projects that had been imagined, these systems are, once again (thanks to recent technological progress and the decisions made by the ITU twenty years ago), now being rolled out. This is one of the few examples in which worldwide regulations were a step ahead of technology.

[1] This article has been translated from French by Noal Mellott (Omaha Beach, France). The translation into English has, with the editor's approval, completed a few bibliographical references. All websites were consulted in October 2020.

High-altitude platforms by Christine Mengelle

Abstract:
Mainly used at the start for scientific purposes, high-altitude platforms have increasingly attracted interest since the 1990s as a complement to land and satellite networks. At a position above the altitude of commercial air traffic and the jet stream, such platforms — which are easy to deploy and necessitate a minimal infrastructure (networks and maintenance) on the ground — offer an additional advantage: a wide zone of coverage with very low latency. They are, therefore, of special interest for civil or military surveillance operations and for telecommunications in areas isolated by geography or a disaster. Technological progress and a propitious regulatory framework — established since 1997 by successive world radiocommunication conferences (WRCs) — open the possibility of rolling out high-altitude stations in the near future.

Initially used for scientific purposes (meteorology or monitoring of the environment), high-altitude platforms have, since the end of the 1990s, attracted ever more interest as a supplement for the radio connectivity of terrestrial and satellite networks. Positioning these platforms in the stratosphere has major advantages: a broader zone of coverage from a location above the levels of commercial air traffic and strong winds (jet streams).

For three decades, technological progress and better knowledge of the stratosphere have augmented the viability of plans for high-altitude platforms. Since 1997, the regulatory environment has evolved positively, and the ITU has allocated frequency bands on which these new services may be deployed.

The advantages of high-altitude platforms

High-altitude stations have undeniable operational advantages owing to the extent of their coverage (over a zone larger than conventional terrestrial networks) in association with very low latency (compared with satellites). For this reason, they are of special interest for (civilian or defense) monitoring operations and for telecommunications (broadband or terrestrial mobile applications). Another advantage is that these stations can be very easily deployed — with minimal network infrastructure and minimal maintenance on the ground — in isolated geographical areas (mountains, deserts, etc.) or following a catastrophe (earthquake, cyclone, etc.). Besides, they can be easily brought back to the ground for maintenance or modifications (to, for instance, change the platform's assignment or replace its payload with more advanced technological devices).

For these reasons, this type of platform offers an excellent synergy with terrestrial and satellite services in terms of radio connectivity.

Technical conditions and requirements

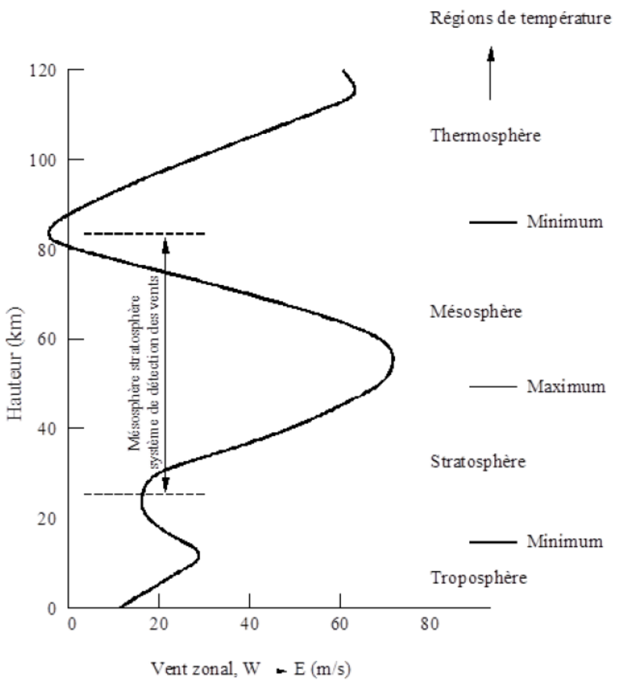
For platforms to operate in the stratosphere, major technological barriers must be lifted in fields as varied as avionics, the efficiency of solar panels, the storage of energy, composite materials and antennas. These barriers have long (since the first programs in the 1990s) stood in the way of developments, but programs in recent years are now focusing on them.

Technical requirements have to be met to operate high-altitude platforms. Since the platform has to maintain a nearly stationary position above the targeted zone on the ground, its altitude is typically about 20 km — above the jet streams (10-15 km) and in a layer of the stratosphere where winds are not so strong. The platforms can then hover or move predictably above the maximum altitude of controlled air space.

Figure 1: Average wind in the upper atmosphere

FIGURE 1

Profil de vent moyen dans la haute atmosphère



Intensité générale des vents zonaux dans la haute atmosphère - répartition verticale à 45° N en janvier (Atmosphère de référence internationale du Comité de la recherche spatiale, Akademie-Verlag, 1972)

Platforms of two major types have been developed that satisfy these requirements: dirigibles (LTA: lighter than air) and drones (HTA: heavier than air). A manufacturer's choice between the two is often a matter of history and, too, a response to requirements related to avionics and the maintainability of the platform in the air.

***Figure 2**: A HAPS HTA on the drawing board*
Source: ©Thales Alenia Space

High-altitude platforms and the ITU

Regulatory requirements about the radio transmissions at an altitude of 20 km must also be met to operate a platform in the stratosphere. The radio spectrum's environment will have to be made viable for both these platforms and other uses of the spectrum.

WRC-97 decided to introduce a new type of station in the Radio Regulations (RR): high-altitude platform stations (HAPS): "*A station located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth*" (RR 1.66A). This was the first time that a decision was made about allocating frequencies for this new service. WRC-97 listed the frequencies for HAPS to operate worldwide: 47.2-47.5 GHz and 47.9-48.2 GHz. In some areas (in particular tropical zones), this allocation has a heavy handicap: heavy rainfall weakens the signals transmitted in this range, and technical conditions make it very hard to access a high-altitude platform. To cope with this difficulty, WRC-2000 identified a set of new frequencies for HAPS: 28 GHz (27.9-28.2 GHz for downlinks, platform-to-Earth) and 31 GHz (31-31.3 GHz, for uplinks, Earth-to-platform) in 23 countries, most of them in Asia, but with no protection from other services using these bands or against interference from them.

On account of the upsurge in mobile networks, WRC-2000 decided, in addition, to authorize the use of HAPS as base stations for international mobile telecommunication (IMT) in the frequency bands between 1.9 GHz and 2.1 GHz. WRC-12 followed up on this decision by allocating HAPS frequencies (2x80 MHz in the 6 GHz band) for "gateway links" to connect IMT base stations. This is limited to five countries, subject to the same restrictions (no protection against interference or claims).

Given the difficulty of sharing bands in the spectrum, WRC-12 also decided to limit HAPS to the frequency bands specified under RR Article 5 (§4.23).

Future uses of HAPS

For a few years now, major advances in technology have been demonstrating the viability of HAPS. Since 2010, several projects have arisen (sponsored by Thales Alenia Space, Airbus and Lockheed Martin).

During WRC-15, on an initiative by Facebook, a new point was added to the agenda for WRC-19: to identify the HAPS frequencies for facilitating access to wideband applications worldwide. After four years of detailed studies carried out at the ITU, WRC-19 allocated the frequency bands 31-31.3 GHz (for downlinks) and 38-39.5 GHz for worldwide use by HAPS, as well as the bands 21.4-22 GHz and 24.25-27.5 GHz in Region 2 (the Americas).

Furthermore, WRC-19 assigned WRC-23 to examine whether HAPS may use the same frequency bands as IMT base stations on the ground in order to extend mobile broadband connectivity to communities that are poorly served or located in isolated areas, below the 2.7 GHz band.

Conclusion

Technological progress in composite materials, avionics, solar cells, batteries and electric motors now enable us to imagine that high-altitude stations will soon be rolled out.

Among its decisions, WRC-19 allocated harmonized bands at the world and regional levels for HAPS (for broadband applications) and foresaw studies about using high-altitude stations as IMT base stations. These decisions contribute to setting up the regulatory framework needed for, and conducive to, the development of these platforms.

Constellations of satellites by François Rancy

Abstract:
Since the start of the space era, geostationary satellites (GOS) have been used to provide commercial telecommunication services. International regulations soon caught up thanks to Radio Regulation 22.2 of the ITU. At the start of the 1990s, plans for constellations with dozens of nongeostationary satellites were made to provide the equivalent of a cellular mobile service for portable telephones. As a consequence, the ITU's World Radiocommunication Conferences (WRC), successively from 1992 to 1997, set up a regulatory framework adapted to this demand, assigned a few hundred megahertz and defined procedures for access to the radio-frequency spectrum based on the "first come, first served" principle. By 1995, plans for hundreds of nongeostationary satellites were being made to offer all countries on the planet access to the Internet. The WRCs in 1997 and 2000 could satisfy the subsequent requests for a spectrum of several gigahertz only by adopting (after surmounting major difficulties) a global approach that replaced Regulation 22.2 with a system that had verifiable, mandatory limits in order to protect the full spectrum shared with geostationary systems. In the first years of the 21st. century, these plans lay dormant owing to the dot-com bubble. Nowadays, technological progress and the ITU's decisions from twenty years ago have set the conditions for launching constellations with thousands of nongeostationary satellites — a rare example of global regulations preceding technology.

From the first years of the space age, geostationary satellites (GOS) have had the upper hand in providing commercial services in spatial telecommunications. The reason is simple: their equatorial position at an altitude of 36,000 km is the only orbit where satellites can stay in a fixed position in relation to Earth. The station on the ground that uses the satellite needs but a single antenna pointed in a single fixed direction in space whereas, in the case of nongeostationary satellites (NGOS), the station needs several antennas that have to constantly change direction to keep connections from being cut off. Furthermore, a system of three geostationary satellites can cover nearly the whole planet, except for polar zones — these satellites are not visible usually beyond 60° latitude. In contrast, at least a dozen nongeostatonary satellites are needed to provide permanent worldwide coverage, and they spend most of their time covering inhabited areas. For these raisons, the orbit of geostationary satellites has for nearly sixty years now been preferred for broadcasting or fixed commercial connections nearly to the exclusion of all other orbits.

Article 22.2 of the Radiocommunications Regulations (RR), effective since the start of the space age, states: "*Nongeostationary satellite systems shall not cause unacceptable interference to and, unless otherwise specified in these Regulations, shall not claim protection from geostationary satellite networks in the fixed satellite service and the broadcasting satellite service operating in accordance with these Regulations.*"[2] Resolution 506 went even farther by forbidding satellites other than geostationary ones on the radio frequency bands allocated to the "*service*" of broadcasting by satellite. It thus keeps nongeostationary systems with fixed-satellite service from using the bands shared between two services. Understandably, these two measures sign a regulatory death warrant for commercial NGOS systems, with the notable exception of the satellites used for mobile services with ground stations. Since their antennas were not pointed in a single fixed direction, these stations could make do with nongeostationary satellites. Since the early 1960s, MOLNIYA, the Russian NGOS system, has been serving polar zones, while most mobile communications passed via INMARSAT's geostationary satellites.

[2] To avoid useless complications, this article uses the RR numbering system in effect since WRC-97. Before this world conference, which overhauled the RR, most current articles already existed but under a different number. ITU (2016) *Radio Regulations*, 4 volumes (Geneva, CH: ITU) available at http://www.itu.int/pub/R-REG-RR-2016.

At the start of the 1990s, the first plans were made for NGOS constellations — Orbcom (35 satellites), Iridium (66), Globalstar (48) and ICO (12) — which were intended to reap economies of scale since an NGOS network would cover right away the whole planet. It would thus be possible to offer the equivalent of a cellular service for mobile telephones, which were just coming off the drawing board.

At WRC-92, the first promoters of satellite constellations successfully voiced demands for access to the radio-frequency spectrum and obtained the allocation "*on a primary basis*" to a mobile service by satellite of 183 MHz of supplementary spectrum below 2.7 GHz, subject to the procedure of coordination (RR Article 9.11A) based on the "first come, first serve" principle between GOS systems, NGOS systems and Earth services. This made room for access to the spectrum along with international recognition and protection. In addition, the 2x34 MHz allocated since the start of the space age to mobile satellite services and used by INMARSAT on 1.5/1.6 GHz were opened to NGOS systems on the same basis.

With this first victory came a bid for a new one. At WRC-95, a decision was made about supplementary frequency allocations on the bands of fixed-satellite service for the links necessary between nongeostatonary satellites providing a mobile service and fixed nodal stations. On account of the difficulties of sharing between GOS and NGOS systems, the application of Article 9.11A meant taking back the bands seldom used at the time by GOS systems, which had few chances of being able to use them later on. The choice made by WRC-95 was for the bands 5091-5250 MHz, 6700-7075 MHz, 19.3-19.6 GHz and 29.1-29.4 GHz — in all, 1.134 GHz of the spectrum shared with earth stations that, too, were subject to Article 911A. As a consequence, Article 22.2 was abolished in these bands.

Figure 3: SaVi (Satellite Constellation Visualization software), http://savi.sf.net/, 2017.
Source: ©L. Wood, P. Worfolk *et al.*

WRC-95 also moved from minor skirmishes about links — a topic with a relatively limited impact that had been well prepared beforehand — into an epic battle. During three world conferences, the battle would be pitched about the issue of NGOS constellations for fixed-satellite service.

In the last months prior to WRC-95, the advocates of Teledesic (Bill Gates and Craig McCaw with the support of the highest level of the US government) sought to convince ITU member states that the decisions expected of the conference on NGOS links for mobile satellite systems would negatively affect the rollout of this constellation of 840 nongeostationary satellites, which would offer immediate access (nearly) for free to the Internet to all countries on the planet. No one in the relatively small community that manages radio frequencies seemed to take seriously a program deemed extravagant owing to its dimensions, price ($10-20 billion) and technological challenges. Besides, this point was not on the agenda for WRC-95 and could not be examined during the preparatory work for the conference. It came as a surprise when, on the first day of the conference, a raised-hand vote proved that the overwhelming majority of member states had clearly understood the message from the two billionaires and that the die had been cast. WRC-95 thus decided to fall in line with the proposal from the United States and opened 1 GHz of frequencies for fixed-satellite service (18.8-19.3 GHz and 28.6-29.1 GHz) to NGOS systems. This was done by following the procedure stipulated in Article 9.11A and abolishing Article 22.2. The European Conference of Postal and Telecommunications Administrations (CEPT), which had stiffly opposed this decision throughout the conference in order to defend the interests of its GOS systems, suffered a severe setback. It only obtained that the lower 20% of these two bands should be brought back under discussion at WRC-97. The CEPT was thus placed in the position of being opposed to the relentless march of technology.

The studies conducted in preparation of WRC-97 concluded that Teledesic, which had registered its demand right after WRC-95 (and, therefore, prior to most of the GOS systems interested in using the band), was incapable of sharing frequencies with others systems, whether GOS or NGOS. As a consequence, the first comer, Teledesic, would be the only party served. WRC-95's decision thus amounted to giving this system a worldwide monopoly on 1 GHz of the spectrum for the provision of Internet services by NGOS systems, since the others bands for fixed-satellite service were still subject to the very tight conditions stipulated in Article 22.2.

The only possible strategy for handling this situation was to open to NGOS systems the part of the spectrum allocated to fixed and broadcasting services by satellite without invoking the principles laid down in Article 22.2 but by setting clear, quantitative restrictions on the "acceptable" level of interference that an NGOS constellation may cause to GOS systems. To be credible, these restrictions would have to be "hard" (*i.e.*, mandatory) and subject to an official verification of conformity by the ITU's Radio Regulations Board. If these limits were exceeded, the rights of the NGOS system to use the bands would be invalidated. To have a chance of success, this strategy had need of a project that would be in competition with Teledesic so that the idea of realizing an NGOS system on this basis would be credible. Thales Alenia Space (at the time: Alcatel Espace) took up the challenge by proposing the Skybridge system. With the backing of the French government, it managed within a few months to convince the CEPT's 48 member states that the best way to protect their GOS systems was to back the adoption of "*hard limits*". The CEPT thus became the champion of progress and competition.

In the groups in charge of preparing WRC-97, the opposition from GOS and broadcasting communities was so widespread that the conference started without any preparatory discussions. On the eve of the conference, the FCC's spokesman explained to the press his organization's absolute opposition to hard limits. The decision to examine the CEPT's proposal was not made till the end of the first week. After three weeks of intense negotiations, the CEPT's arguments rallied a large majority of ITU member states, and WRC-97 adopted the limits[3] for 7 GHz of the spectrum (including the bands allocated for fixed-satellite service and satellite broadcasting). Furthermore, it limited the restrictions of Resolution 506 to broadcasting by satellite. However these limits were temporary since it WRC-2000 was assigned to re-examine them.

After two years of in-depth studies that finally cleared up opposition, WRC-2000 modified these limits, usually by loosening them, and added stricter operational constraints that were to be verified in operating conditions. It also added special measures to protect the very big ground stations of GOS systems. What remained was to develop the validation software for the Radio Board to use to verify the conformity of the proposed NGOS systems with the limits set.

WRC-03 completed the job by opening an additional 1.3 GHz of the spectrum to NGOS systems (on 6 and 4 GHz). Article 22 now covers nearly all the bands used commercially for fixed-satellite service.

At the end of the millennium, the dot.com bubble wiped out most of the plans for NGOS systems with fixed-satellite service. Teledesic's rights expired, thus shutting the door on the possibility of an NGOS system on the allocated frequency band (since it would now be occupied by GOS systems) and confirming that WRC-95's regulatory solution on coordination had not proven effective in the long run.

Since 2015, advances in the technology for launching satellites have sparked new interest in NGOS constellations for fixed-satellite service, the purpose still being to offer the Internet to zones that, not covered by fixed or mobile networks, represent the largest part of the earth's land surface. Constellations of hundreds of nongeostationary satellites are now being launched, in particular: OneWeb (648 satellites built by OneWeb and Airbus and launched by par Ariane, Soyouz and Virgin Galatic) and Starlink (1600 satellites built by SpaceX and launched by its Falcon 9). This deployment, possible thanks to radio regulations adopted twenty years earlier, is one of the very few examples of worldwide regulation being a step ahead of technology. The Radio Regulations Board's validation software, its development having been placed on hold in 2003, was completed in 2018. Most of the proposed NGOS systems have been found to be in conformity with the regulatory limits.

To provide for the future of NGOS constellations, WRC-19 added to regulations the following decisions:

- a precision about the regulatory deadline for operations following the initial demand for access to the spectrum in order to preserve the rights thus granted: 10% of the satellites of the constellation will have to be launched within two years and not later than seven years of the date planned for using the network, 50% within five years, and 100% within seven years.
- opening 9 GHz of the spectrum to NGOS systems in the bands 40 and 50 GHz, under conditions similar to those set by WRC-97 and WRC-2000, the hard limits applicable in Article 22 containing binding levels of degradation of the performance of GOS systems.

[3] Precisely, under Article 22 of the RR, the limits were about the equivalent power flux density (epfd) produced by: *a)* all satellites in the constellation and that has to be verified "*at any point on the Earth's surface visible from the geostationary-satellite orbit*" with a set of antennas of a given ground station in the GOS system pointed toward any point in the GOS orbit and for percentages of set times (epfd↓); and *b)* "*at any point in the geostationary-satellite orbit from earth stations*" (epfd↑) of the NGOS constellation; and *c)* "*at any point in the geostationary-satellite orbit by emissions from all the space stations in a non-geostationary-satellite system in the fixed-satellite service in the frequency bands listed*" ($epfd_{IS}$). The calculations necessary to verify an NGOS system's conformity with these limits imply building a model of operation of the whole NGOS constellation. For these calculations to be feasible, each satellite in the constellation is presumed to beam permanently at the maximum of its capacity, a restriction that improves the protection for GOS systems.