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# Megaconstellations: Crowded, Contentious and Competitive

## Introduction

The rise of megaconstellations has set a new precedent in orbital congestion, simply as a result of the increased number of satellites involved. According to the United Nations Office for Outer Space Affairs, since the launch of Sputnik 1, 17,263 objects have been launched into space,[1] of which 11,330[2] individual satellites were orbiting the Earth at the end of June 2023, representing a 37.94% increase since January 2022. Although we have become accustomed to the novelties of space communication, until now it was characterised by a steady development. Now, however, its pace has changed: until 2020 only 10,308 were launched, but the last 3 years has seen a further 6,995 objects launched, which means 40.29% of all objects in this period. Most of these objects are communication satellites, which are deployed in increasingly connected systems in low Earth orbit (LEO).

Although the rapid development of the LEO constellation has contributed to numerous human activities, such as communication, navigation, remote sensing, the deployment of these constellations has strained not only the limited natural resource of frequencies, but also the scarce resource of orbits. The deployment of these constellations is an issue of regulation and meticulous planning.

International discussions are ongoing on space debris and space traffic management, but less is known about the other thorny problem raised by these constellations: interference. The LEO constellations possess the characteristics

[1] Our World in Data s. a.

[2] Pixalytics 2023.

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of other, better known geostationary satellite constellations, including a wide range of distribution and an enormous scale. While the development of these constellations is bringing revolutionary changes to the progress of the global space industry, the problem with these satellites takes us back to the basics of telecommunication: not to cause harmful interference to another radio system.

The problem of interference is not specific to satellites, it is omnipresent in every radio system, although satellites might suffer more from such disturbance, whether intentional or not. The electromagnetic field provides two windows to Space or from Space to Earth: one is light, the other radio waves. Only a certain length of radio waves can pierce through the atmosphere of the Earth: from 2 GHz to 40 GHz, which means that only this rather narrow bandwidth facilitates the communication between all satellites and other human made space objects (i.e. space probes, rockets) and the Earth or indeed the Universe.

Before investigating the problems of LEO satellites, it is important to understand the international mechanisms that allow the peaceful coexistence of different systems: the international frequency coordination of the International Telecommunications Union (ITU).[3]

## WHAT IS FREQUENCY COORDINATION?

Frequency coordination is a procedure carried out by operators via their respective administrations to avoid potential harmful interference between new and existing wireless systems, stations or applications. The procedure is applicable to all radio systems, providing there is a possibility of an impact that extends beyond national borders. Article IX of the Outer Space Treaty[4] requires international consultations in cases when potential outer space activities or an experiment planned by a State or its nationals might cause harmful

[3] The International Telecommunication Union (ITU) website: https://www.itu.int.

[4] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, 1967.

interference. It should also be noted that the ITU coordination procedures for objects launched into space preceded the Outer Space Treaty, as these procedures were introduced as early as 1963.

The purpose of the coordination:

a) enabling the effective operation of existing radio stations or systems, as well as any new stations or systems
b) the recognition of this new station or system, i.e. protection against harmful interference of stations or systems to be installed in the future

Since the beginning of the space age, the ITU has identified the needs of the space sector and from 1959 onwards it has provided the spectrum requirements for the growing space industry. The ITU is a specialised agency in the UN system, consisting of representatives of the signatory Member States along with representatives of academia and private sector, thus provides a synergistic approach to the studies and proposals which are discussed and adopted in various forums.

It is universally acknowledged that the most elaborate and detailed form of the regulation of space activities concerns space communication. As part of telecommunication, space communication is regulated within the framework of the International Telecommunications Union (ITU). The most important document in this field is the Radio Regulation,[5] an international treaty governing, among other matters, the use of the radio spectrum, the procedures for obtaining access to spectrum and orbit resources, and the recording of these in the Master International Frequency Register – MIFR).[6] The aim of this legal framework is to govern the allocation of these resources among potential users, the provision coordination mechanisms among users to avoid conflict, and the protection of orbital resources from detrimental activities.

It is important to note that Member States are represented in these procedures by their appointed national administrations, which may be either

[5] *Radio Regulations* 2020.
[6] *Rules of Procedure* 2021.

a ministry, a government department or a national regulator, which is armed with all the instruments necessary for implementing the obligations set out in the ITU documents.

The orbital position of a satellite determines the area where its signals reach the Earth and affects the technological possibilities of the satellite service. Until the second half of the 2000s, satellites operated mostly in a geostationary orbit, an altitude of approximately 35,800 km in the plane of the equator. At this altitude, each satellite rotates around the Earth's axis once every 24 hours and thus appears to remain stationary above a fixed point on the Earth. This remains the scarcest orbital resource.

From the 2000s onwards, however, technological developments have brought a new era for satellites, enabling communications satellites to operate from low Earth orbit. This orbit – which is between 500 and 2,000 km altitude from the Earth – provides low latency by the use of smaller communication satellites. However, from this orbit the coverage of each satellite is limited, so a network of several satellites or "constellation" is needed to ensure continuous service.

Deploying satellites into orbit represents a limitation, since it is only possible to obtain the right to use satellite positions and the associated frequencies within the institutional framework defined by an international convention – in favour of the requesting state. The state transfers this right to an organisation or company if it is entitled to it through its own national licensing procedures. By launching the satellite, this organisation or company performs space activities, which may be implemented under continuing state supervision in accordance with Article VI of the Outer Space Treaty.

Temporary use of the spectrum is implied by the deployment of the satellites into orbit, i.e. for a period equal to the life of the satellite – either on the basis of *a priori* plans or within the framework of a coordination procedure aimed at the international negotiation of frequency use, with the state that initiated the procedure receiving the right to use the given orbit and the orbit being granted to an organisation or a company – mostly an entity under the state's jurisdiction – by the national authority. The procedure is carried out by the ITU together with the communications administrations of the countries concerned. The satellite systems included in the *a priori* plans are the positions in the geostationary orbit assigned to each country and the corresponding frequencies, which can only be owned by the given state. These states can send a satellite to that position at their discretion, either by means of their own (national) operators or leased to an operator registered to another country.

As noted earlier, frequency and satellite orbits are precious, scarce and limited natural resources, which led to two major mechanisms being developed and implemented for sharing orbital and frequency resources:

a) *a priori* planning procedures
b) the first come, first served coordination procedures

The BSS (Broadcast Satellite)[7] and FSS (Fixed Satellite) Plans[8] were created to prevent the depletion of satellite positions. These plans provide each country with an opportunity in a specific frequency range to implement a satellite service covering the country in the future without having to ask for the consent of other countries. The planned frequency bands are those which countries can use for their own satellites. The problem with these plans is that they focus on satellites in geostationary orbit, since they were developed in the 1980s and based on the technology of that time.

The rest of the satellite orbits – orbital slots or planes – are allocated by coordination procedures, where latecomers have to consider the requirements of the first filed satellite network. The coordination procedure is a mandatory process of negotiation between national administrations and the ITU. The goal is to achieve the most efficient use of the orbit and spectrum resources through a controlled interference environment in which satellite networks can operate and meet requirements that include the provision of GSO networks in all services and frequency bands and non-GSO networks in certain frequency bands.

Although satellite frequencies are allocated globally, differences exist in the three regions of the ITU concerning frequency allocation. Article IV Section 5 of the Radio Regulations contains the frequency allocation table, which defines

7 *Radio Regulations* 2020: Appendix 30.
8 *Radio Regulations* 2020: Appendix 30B.

for each frequency band which radiocommunication services are allocated for which purpose in all three ITU regions. (For the purpose of radio frequency allocation, point 5.2 of the Radio Regulations divides the World into three regions: Region I: Europe, Africa and Russia; Region II: the Americas; and Region III: Iran, Pakistan, India, China and East Asia, Australia, New Zealand and the Pacific Islands south of the Equator.) While the ITU member states may differ in their own frequency allocation tables from those contained in the table of the International Radio Regulations, they may not thereby cause harmful interference to another ITU member state, which applies the allocation according to the Radio Regulations.

The Radio Regulations define the uses of individual frequency bands that receive international recognition. Within each frequency band, radio telecommunications services are divided into 'primary' and 'secondary', either globally or regionally. By definition, stations falling in the secondary service category may not cause harmful interference to existing or future stations of the primary service, and may not claim protection against harmful interference caused by these stations (Radio Regulations, Article 5.30).

The Radio Regulations specifies procedures by which a satellite network's frequency assignments can be registered and submitted by its national administration, and hence to the ITU to obtain international recognition of the radio system. Through these procedures all national administrations belonging to the ITU are informed of the use of the frequency assignments, while ensuring that they are taken into account in any future planning conducted at the national, regional or international level. Importantly, ITU registers the frequency assignments of a radio system along with the position of the station – whether it is terrestrial or satellite/space station – and provides information to the administrations affected by the service area.

It is also important to note that the ITU does not authorise the use of frequencies, but registers the allocated frequencies and the associated satellite orbits in order to avoid interference, the authorisation of frequency use and the supervision of the service provider are the responsibility of the national authorities, mostly the national administrations.

The powers of the national authorities vary, but they are uniform in that they regulate the method of awarding the right to use frequencies based on technical aspects, which can range from an individual licence to auctions (tender or concession).[9] The states have devices corresponding to their own legal system regarding each frequency, which is typically state property (in some cases the property of the king or queen), while the allocation of satellite orbits also follows a similar principle, although all states prioritise uninterrupted cooperation during use. Most spacefaring countries opted for individual licences on the principle "first come, first served", as in the U.S., the U.K., Luxembourg or France, while Brazil and Mexico use auctions to award licences.

## WHAT IS THE PROBLEM WITH MEGACONSTELLATIONS? INTERFERENCE, OVERFILING, RADIO ASTRONOMY

A major source of potential problems for current satellite systems is that the radio spectrum the LEO constellations wish to use is already in use by existing geostationary (GEO) satellites. Consequently, a situation may arise in which a constellation of satellites orbiting the Earth in low Earth orbit (LEO) fly through the beam of a GEO satellite and the transmission occurs on the same frequency, thus causing interference to users on the ground underneath. Considering the shape of the Earth, this is only an issue when the LEO satellites are relatively close to the equator. Nevertheless, LEO satellites are in inclined orbits and thus cross the equator twice on each orbit, and the orbit period, mainly depending on the altitude, varies in the range of 90–120 minutes, so this remains a problem.[10] In addition, most of the LEO – and also high Earth orbit (HEO) – constellations consist of 3 to 5 satellites using the same orbital plane, so interference can potentially occur more frequently.

However, existing GEO systems are not the only potential sources of radio frequency contention. As the number of megaconstellation satellites grows,

[9] Nordicity 2010.
[10] Eves 2021.

there is an increasing probability that they will interfere with each other. It should be reasonably clear that, even from LEO, hundreds or even thousands of satellites are not needed simply to provide users with a line of sight to a satellite. The reason why the megaconstellations are so large is that each satellite is only designed to provide services in a relatively small region immediately beneath its ground track. The sizes of these satellites' service areas (footprints) also dictate the range of angles in which the user terminals must operate in order to maintain contact with the constellation. Table 1 shows the largest satellite constellations – operating (first figure) or filed (second figure) – with their altitude and the frequency band used.

Table 1

*The largest satellite constellations*

| Name | Number of satellites | Orbital altitude | Band |
|---|---|---|---|
| Starlink | 5,399/42,000 | 340, 550–570 km | Ku, Ka, E |
| OneWeb | 636/648 | 1,200 km | Ku |
| Telesat Canada | 3/198 | 1,000 km | Ka |
| Swarm | 189/150 | 500–550 km | VHF, UHF |
| Kuiper | 2/3,236 | 590–630 km | Ka |
| Guowang (China) | 0/12,992 | 150–300 km | Q, V, Ka |
| Cinnamon (Rwanda) | 0/337,320 | 500–700 km | Ku, Ka |

*Source:* Compiled by the author.

The sheer number of these constellations creates serious safety and long-term sustainability challenges to the use of low Earth orbit. According to the ITU's database, permits for more than 300 constellations representing over one million satellites were filed between 1 January 2017 and 31 December 2022. Among these 300 constellations, more than 90 comprise over 1,000 satellites each, with the largest single filing, Cinnamon-937 involving 337,320 satellites.[11] Congestion in LEO orbit might lead to the potential collision of the satellites

[11] Falle et al. 2023: 150–152.

of the various systems, which may cause a significant increase of space debris. As approximately 89% of the active satellites are located in LEO,[12] and the majority operate at orbits lower than 1,000 km, there is a high probability of collision. Nevertheless, the details of the problems of space debris or space sustainability are not the topic of this paper.

It is likely, however, that these constellations may not be launched, or at least not as they are planned. There are many reasons why satellite projects may not come to realisation. Apart from funding problems, development and planning issues and the lack of governmental support are the major ones. Filings to the ITU can also be a calculated move on the part of companies or governments, either to attract investors or to later be able to sell orbital rights, or simply "spectrum warehousing", in order to use these permits later if customer demand increases. Overfiling is a recognised problem, and the space industry has already developed practices to provide spectrum warehousing by splitting their satellite constellations between multiple administrations and multiple filings. For example, SpaceX's Starlink Gen2 constellation was submitted across approximately 22 filings, by three administrations – Norway, Germany, the United States and recently Tonga.[13]

Since different nations have different approaches to and regulations for ITU filings, naturally, the companies prefer to consider all the factors that could provide them with a favourable regulatory environment, in a similar way to flag of convenience in the maritime sphere. Small nations provide registration as required by international law, but their national law includes the bare minimum and is hardly ever enforced, while, as ITU Member States, the accessibility of the ITU's processes for securing radio frequency spectrum offers nations a way into the fast-growing high-tech sector. To counteract overfiling, administrative measures were adopted at the ITU's World Radio Conferences during the last 25 years. To reduce speculative filings, due diligence rules were established in 1997 (RES 49),[14] which require notifying administrations to submit information

[12] Union of Concerned Scientists 2023.

[13] Falle et al. 2023: 150–152.

[14] *Radio Regulations* 2020.

such as the planned spacecraft manufacturer and the launch provider to the ITU. Another administrative measure was adopted in 2019, the "milestones" approach, where operators must launch 10% of their constellation within two years, 50% in five years and 100% within seven years after the initial filing. If they fail to launch enough satellites before these deadlines or fail to finish the constellation within seven years, their spectrum rights are limited proportionally to the number deployed before the allotted time ran out.

The negative effect of these constellations on radio astronomy is also a source of concern for scientists. Various instruments have been implemented to protect the radio telescopes, which are mostly passive antennas, thus being subject to the Radio Regulation. The ITU's World Radio Conference in 2019 adopted a resolution stating that megaconstellation satellites must be equipped with filters that specifically aim to protect the radio telescopes which operate in the frequency range from 10.6 to 10.7 GHz. Undoubtedly, it is hoped that the active transmissions from satellites can be managed, although, a rather more contentious issue is the possibility that the increased quantity of megaconstellation hardware in Earth orbit will cause inadvertent interference simply by being deployed in the orbit. An experiment performed by the Murchison radio telescope array in Australia has demonstrated[15] that terrestrial radio signals (including FM radio stations) can be detected by reflection from objects in LEO. While admittedly the target object in the Australian experiment was the International Space Station (ISS), which is by far the largest man-made object in space, the implications of this are serious because it raises an important question, namely, is there a place on Earth which is radio quiet?

Apart from the potential problems arising in the radio frequency domain, the megaconstellations are also creating issues at optical wavelengths. One issue that has received extensive coverage is the fact that Starlink's satellites are creating "artifacts in astronomical observations".[16] The company recognised

[15] TINGAY et al. 2020.
[16] RAWLS 2023.

this issue and sought to address it by conducting experiments to reduce the reflectivity of the satellites' antennas, installing sun-visors to shade highly reflective components and changing the attitude of their satellites in the orbit-raising phase of the mission. Paradoxically, one of the more effective measures taken is the lowering of the orbital altitude, since this reduces the amount of time that the satellites spend in twilight conditions (where the ground is in darkness but the satellites are still illuminated by the Sun). This also addresses the problem that arises for astronomers searching for near-Earth objects, as reducing the time megaconstellations spend in twilight will enable more efficient searches for these targets.

Another serious concern is the influence of megaconstellations on global space activities. The megaconstellations in LEO form a high-density 'space grid' in the near-Earth space, which tightly wraps the Earth in multiple layers, causing these orbital zones to become more crowded. As the number of LEO satellites has grown dramatically, the risk of collision has grown, significantly reducing the extent of global safety launch windows. Potential collisions may have disastrous consequences, leading to the eventual collapse of the space environment.

## THE DILEMMA OF LEO SYSTEMS

The question arises, why is LEO orbit so important, and why do so many new space operators opt to place their equipment in this orbit?

The answer lies in the efficiency of the satellite networks, which makes these orbital planes so precious. As the performance of a satellite network depends on the orbit the satellite is deployed in, the distance from the Earth affects the capabilities of the satellite. Although satellite networks in LEO orbit require the most satellites to build up a constellation and the area covered by a single satellite is relatively small, the system as a whole provides a very low latency

(~50 m/s) compared to satellites in GEO (~700 m/s) or MEO (~150 m/s) as well as offering coverage of the polar areas, where the GEO satellites may have limited or no line of sight.[17]

The distance to orbit is also a determining factor of the most important variables of commercial satellites: the cost of launch. In case of GEO satellites, the launch cost comprises more than one third of the total cost of the satellite, while LEO satellites are smaller, lighter, and the cost of launch per satellite is lower. On second glance, however, it becomes clear that this may not be the case for the whole constellation, which may comprise hundreds or even thousands of satellites to allow it to provide uninterrupted service. When compared with a GEO satellite with an active service life of 20 years, the cost to deploy a LEO satellite system is significantly higher, almost tenfold. As LEO satellites have a shorter operational lifespan, typically from three to five years, they therefore need more frequent replacement, and also require more complex tracking and control systems, thus, from this perspective these constellations might seem less attractive.

As for the frequency bands, most LEO systems use Ka (12–18 GHz), K (18–26.5 GHz) and Ku bands (26.5–40 GHz), as these bands are the most advanced in technology. Very low latency is a unique characteristic of LEO constellations, which supports real time communications, not just in voice and data services, but also broadband internet access in remote or rural areas, offering global coverage.

Data collection is the main focus of the Earth observation applications, which also operate in low Earth orbit. The high-resolution images and extensive data provided by these satellites are invaluable for weather prediction and for studying climate change as well as disaster response to recovery efforts. These capabilities of LEO satellites are an invaluable asset for surveillance and reconnaissance, together with satellite navigation and positioning, as well as for agriculture and forestry.

17 Digital Regulation Platform 2023.

## ECONOMIC CONSIDERATIONS OF OPERATORS

The continuous development of space technologies made the emergence of space communications possible, and by the late 1980s the first private satellite operators, including PanAmSat and SES, were already competing with established market players operating in the form of intergovernmental organisations. The liberalisation of the communications market by the late 1990s led to the privatisation of most intergovernmental satellite organisations and marked the beginning of the commercial use of outer space.

However, this did not mean that the state's role in the use of space ceased, but rather that the centre of gravity shifted: while previously the state actors determined the direction and methods of space research and use, from the 1990s, certain areas of space research and some – in particular, non-civilian – uses remained in the hands of the states while commercial use became free under strong state control in a large proportion of the world, which led to the emergence of global service providers.

The consequences of the state's involvement in the background can be very serious for the state's sovereignty. On the one hand, the technological knowledge acquired puts each company or group of companies in a monopoly position, and thus defence investments become completely vulnerable to these companies. The advance of artificial intelligence shows that technology-developing companies with strong capital are already determining the evolution of the market, with no state having any influence on the price and distribution of their products and developments, which puts state customers in a vulnerable position. On the other hand, the basic interest of companies is profit maximisation, not loyalty, so it can easily happen that opponents have the same military equipment at their disposal. The third and last consequence to be mentioned is that multinational companies dominate the global market. Their size and influence are greater than the capabilities of a small or medium-sized country, and they are also able to represent their interests more effectively. Currently, multinational companies prefer to enforce their interests through individual countries, but it is expected that these companies will realise the potential of their political influence related to their financial capabilities, and many consider that it is only a question of time before they act openly to assert their interests.

The situation is more nuanced by the fact that multinational companies, applying the practice of "forum shopping", settle in the territories of states in which entering the market is subject to predictable conditions, the risk of their investment is not too high, and the regulations of the given state do not demand too much of their income. In the satellite sector, following the communications liberalisation of the 1990s, this process only accelerated. As noted earlier, this trend is supported by the ITU's processes for frequency filings, where the flag of convenience is becoming more easier to access via the procedures of national administrations.

Based on all of this, the market role of multinational companies raises serious questions of sovereignty and security policy, especially if the company's products involve key military technology or the multinational company provides a service that is vital for the protection of the state's security.

Although multinational companies are not completely global and cannot be understood without considering the country where their headquarters are located, they can nevertheless represent a significant force within the given country. The obligations of multinational companies are determined by the internal legal framework of the state where their headquarters are located, but due to their size and activity, a rapid change of circumstances, i.e. a change of the state of their headquarters, is not possible in practice. Due to their size alone, multinational companies have a clear financial, economic and even political influence on the states in which their headquarters or even their subsidiaries and branches operate. This assumes that the multinational company's settlement in the given state was preceded by the consent of the home state, and that the multinational company recognises the sovereignty of the given state over itself. However, this does not entail absolute control over the entire activity of the multinational company, as it is possible to control only certain activities related to the given state.

Nevertheless, in order to preserve their sovereignty and enforce their security policy goals, states pursue and will continue to pursue policies that satisfy the needs of multinational companies, if they have products and services that are important to them. In connection with the space race, it can be stated that the satellite sector is mostly the domain of multinational companies that have served the security policy interests of a state almost since their foundation and which sell their capacities above that on the global market. Since there are no binding operating standards to it, the space race is also intensifying due to the rapid development of technology. Moreover, the states participating in the conquest and use of outer space act according to the ancient and overriding state interest (raison d'état) in order to protect their sovereignty.

## REGULATORY CHALLENGE

In the field of satellite communication, the youngest of the communication sectors, a global market has thus apparently been established, and access to technology, development and innovation significantly influence the competition in this global market.

The global market for satellite communications cannot be managed within the framework of current international trade cooperation which was defined in the early 1990s. The general principles of competition regulation and the special principles regarding electronic communications, as well as the basic principles for the reasonable, efficient and economical use of frequency and satellite orbit appearing in the ITU system determine the frameworks that must also be followed in the regulation of space communications, although, this is not possible without the existence of an international organisation with appropriate powers.

Satellite communication operates in an international market that aims to provide end users with a low-cost, unified communication option capable of covering a region or the entire Earth. Unlike terrestrial networks, satellites can provide service almost everywhere: in both urban and rural, congested or sparsely populated areas alike.

Many functions that guarantee and protect the interests of the licencing state or the customers are difficult or impossible to implement in the case of a global service provider. Although the licensing state must request territorial consent from the relevant state for purposes of frequency coordination, it does not mean that the satellite will actually provide any service in the consenting state. The provision of electronic communication services in the territory of the EU is subject to notification, and many consumer protection and data protection rules are connected to this. In the absence of notification, the authority supervising the service is unable to enforce the provisions established to protect its own citizens, even in case of a global service notification, as national rules can only be enforced based on the high degree of cooperation of the service provider.

This uniformity also constitutes the principal regulatory challenge, since satellite service providers need uniform rules to apply in the area covered by the satellite, but the services are based on licences issued by individual states and on the frequency they provide. Although regional regulatory forums operate, such as the European Conference of Postal and Telecommunication Administrations (CEPT) which facilitates harmonised policies, strategies and standards, or the Inter-American Telecommunication Commission (CITEL) which recommends framework regulation for certain technologies, the implementation of these instruments still lies in the hands of the member states of these regional organisations.

It is universally acknowledged that the satellite industry is one of the most dynamically developing sectors in today's economies, providing innovative technology and new services. However, market access is dependent upon an understanding of the regulatory landscape. As states have the authority to establish their own national rules for the use of the frequency spectrum, they are obliged to manage the spectrum in a way that is rational, economical and fair,[18] while taking a vast number of measures to serve their national interests.

[18] ITU Constitution 2022: Article 44.2 (196).

The existing licencing processes are designed for traditional satellite services, and may not be suitable for the deployment of more innovative services within shorter timeframes. As mentioned earlier, the spectrum allocation processes are not globally harmonised, which means that deploying a new globally reachable satellite system is complicated by the different regional regulations involved. Efficiently managing spectrum usage while avoiding interference is also crucial, not just between satellite networks, but also between satellite and terrestrial networks, as in lower frequencies the usage may overlap.

## FUTURE TRENDS

Emerging technologies and trends define the future of global communication, especially in the satellite sector. As 5G technologies reshaped communication, the seamless integration between ground and space networks became a reality. Integrated hybrid systems have the advantages of both systems: they have high capacity and low latency, similarly to terrestrial systems, while offering the global coverage of satellite systems. This technological breakthrough is transforming the face of terrestrial communication networks today.

A powerful synergy of complex communication systems is provided by "multi-orbit" satellites and terrestrial networks, that can satisfy the changing consumer habits, which – with the increasing demands of consumers for continuous "online" presence and services "on-demand" – lead in the direction of the convergence of the sectors of the telecommunications industry.

Multi-orbit satellite systems are changing the global satellite market, as GEO satellite operators combine with MEO or LEO operators to diversify their services. The use of multiple orbits enables operators to optimise their performance across different networks. With GEO satellites offering high capacity, MEO and LEO satellites providing low latency and global coverage, the demands of end users for reliable service, cost effectiveness and high speed are best served. The mergers and collaborations taking place on the global market show that established operators are opting to deploy multi-layer satellite systems, either by building their own constellations (like Telesat[19] or SES[20]), or by merging their capacities (like Eutelsat-OneWeb[21] or Viasat-Inmarsat[22]). Apart from the mergers and collaborations of the satellite operators, the traditional telco companies[23] are also reaching out to complementing satellite networks, since the fibre technology is widely available at densely populated areas, whereas satellites services do not have the capacity to provide that level of service, and fibre is not an option for most rural or strongly segmented areas.

The merger of satellite operators is a complex process that involves various legal, regulatory, financial and operational considerations. Mergers in the communication industry often, particularly in the satellite sector, require regulatory approval from relevant authorities, to ensure that the consolidation does not result in anti-competitive behaviour, and that it complies with national and international regulations. Regulatory bodies may assess the impact of the merger on market competition, pricing and overall industry dynamics, while also scrutinising satellite operator mergers from a national security perspective. If the satellite services are critical for national infrastructure or defence, the regulatory authorities may assess the potential impact of a merger on national security before granting approval.

Consolidations and mergers often involve streamlining operations, eliminating redundancies, and improving the overall efficiency of a company, which can lead to a more agile and cost-effective organisation capable of responding to market dynamics more effectively. Moreover, merged companies may have extra resources available to invest in research and development, fostering innovation and the integration of advanced technologies, and resulting in the development of more capable and competitive satellite systems.

19 Dalvi 2023.
20 SES 2023.
21 Rainbow 2023.
22 Jewett 2023.
23 Wood 2023.

Another benefit of mergers in the satellite sector is that merged satellite operators may be able to optimise their use of spectrum and orbital slots, potentially leading to more efficient utilisation of resources. This optimisation can be important in addressing the growing demand for satellite services and mitigating concerns about orbital debris.

Although these rapid technological developments have facilitated a reduction in satellite operational costs and made satellite communication more widely available, reaching profitability in the short term remains a challenge, since launching and operating a satellite network is an extremely capital-intensive investment. For this reason, the market demands for high-bandwidth, low-latency networks to satisfy customer needs may best be met via multiple solutions provided by multilayer networks. The most rapidly technologically developing companies are mostly small and thus lacking funds, while established operators are searching for new methods and new markets to maintain profitability. All these circumstances strongly suggest that the consolidation of the satellite communication sector is inevitable.

Apart from the market consolidation of the satellite operators, the advancement of technologies contributes to the changes of production and usage of equipment. Advancing technologies for user terminals contribute to decreases in cost, while miniaturisation has led to smaller, more efficient terminals with higher performance. As developers aim to create more user-friendly, customer-oriented solutions, self-installing equipment and terminals are taking over, further reducing costs by eliminating the need for professional installation and maintenance. However, this scenario will influence the existing regulatory framework and its implementation, as this increase in the amount of equipment and terminals leads to the expansion of spectrum demands, causing further congestion in the limited frequency bands and increasing the possibility of interference. As equipment and terminals for satellite communication are not in all cases exempted from licencing in the state where they are used, the sheer number of these devices can lead to lingering licencing processes, which also implicates that regulators will have to reshape their licencing procedures.

## CONCLUSION

While it is important to emphasise that the management of satellite radio frequencies cannot be separated from the electronic communication system, as it is an integral part of it, due to its global nature, some aspects of this management require regulation that is independent of sovereign states. The independent regulatory demands involve special requirements for a new communications sector, which is not related to telephone and broadcasting services and does not necessarily mean a competitive market for national companies, but instead a complex system of global service providers. These systems cover the entire range of ICT services, in addition to providing both the infrastructure and the device or terminal for the users.

Multiple stakeholders and international operators are challenging the borders of the current regulatory landscape, a landscape in which regulators have to perform a delicate balancing act between protecting the incumbent services and operators while at the same time supporting technological advancements. Maintaining technology-neutral policies and goals, while converging towards a certain level of regional harmonisation to foster innovation, while at the same time ensuring efficient spectrum use gives regulators a thought-provoking and unique opportunity to develop new approaches.

The more congested the orbital planes around the Earth become, the more forward-thinking regulation will be necessary to ensure seamless, uninterrupted service. With the accessibility of myriads of LEO satellites and the technological innovation they represent, the regulatory landscape goes beyond technological aspects and encompasses new issues such as safety, security, privacy and regional harmonisation. This complex regulatory challenge cannot be faced by the regulators alone. Synergies need to be created and maintained between stakeholders at all levels, since space is a global commons. Developing and harmonising regulations across different countries and regions is a challenge that needs to be overcome to ensure the responsible use of space resources, balancing the interests of various stakeholders, ensuring equitable access and avoiding harmful interference.

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