2025

Report on **Space**

User Needs and Requirements

#EUSpace

EUSPA

EXECUTIVE SUMMARY

This report aims to enhance the understanding of GNSS receivers for space assets in the Space market evolution, strengths, limitations, key technological trends and main drivers related to the uptake of GNSS, EO and SATCOM services across the EUSPA Space Market Segment. These elements are essential to frame the appropriate technology and service offering development against the requirements of the respective users.

Key trends and market evolution

The GNSS market for space users keeps evolving extremely fast, introducing new technologies and reducing costs, resulting in the provision of new products and services that have broadened the existing space user community. This trend has been triggered by the ongoing deployment of **mega constellations on Low Earth Orbits (LEO)**, aimed at competing with other orbit constellations and primarily driven by SATCOM needs of high-data, low latency and global coverage. In addition, with the proliferation of smallsats and cubesats, **space-based Earth Observation services** are developing faster due to space-based sensing – e.g. GNSS-Reflectometry –and tracking techniques – of space assets – derived from spaceborne GNSS receivers, which improves data quality and provides already processed data.

Looking beyond, the **lunar exploration** continues to be a high area of interest in deep space, with the objective to set permanent human presence on the Moon. In fact, the recent lunar mission's LuGRE has demonstrated that GNSS capabilities can support early operations by successfully acquiring Galileo and GPS signals for the first time in History – both during transit through cislunar space – and specifically testing Galileo services such as OSNMA and EWSS. These results underline the relevance of Galileo components for future lunar missions, and the prominence that the EU industry landscape is playing in this innovation field. In parallel, initiatives are being developed for future lunar systems aiming at benefiting from GNSS in early operations, and ensuring future interoperability across deployed systems.

This evolution reflects a broader expansion of the segment, driven by the evolution of space applications and by the progressive extension of GNSS capabilities toward reliable Positioning, Navigation and Timing (PNT) services in all orbital regimes, including beyond-MEO orbits and cislunar space.

All these increasing trends position the Space market as **a critical domain for national security,** with recent initiatives launched at EU level for the provision of autonomous sovereignty secure communications (GOVSATCOM, IRIS^2)**.** In line with this criticality, the monitoring of objects orbiting the Earth is a key sustainability aspect, due to an increased risk of collision that needs to be monitored and mitigated **via SST.**

Drivers for users' requirements

From the GNSS perspective, the Space market segment is determined by the following main drivers:

- **Accuracy:** GNSS is considered a key enabler of accuracy in space missions, with new services and techniques aiming at improving the performance.
- **Time-to-first-fix (TTFF):** lower TTFF increase improves power performance onboard spacecraft, opening the door to new applications.
- **Cost advantage and Simplicity:** lower cost and simpler architectures result from using GNSS receiver for various functions, including navigation, timing or even scientific purposes.
- **Interoperability**: is crucial for users above the altitudes of GNSS constellations, where the availability and power levels of GNSS signals are compromised and only a multi-constellation solution guarantees the usability of GNSS.
- **Timing for Galileo:** supporting synchronization of onboard subsystems, accurate time-tagging of mission data, and alignment of navigation and control functions.

To support the needs of the community and the technological evolutions, **Galileo continues incorporating new services.** The Galileo's High-Accuracy Service (HAS) has been available since January 2023, expected to support highly accurate real-time navigation products and lower TTFF with upcoming evolutions. In fact, with the first compatible spaceborne GNSS receivers already in the market, a higher uptake of this service is expected in the years to come. Other services such as the Open Service Navigation Message Authentication (OSNMA) or the Galileo Emergency Warning Satellite (EWSS) services are expected to prove valuable in the future.

Within this evolving landscape, several challenges raise to continue the enhancement of performance and reliability. Antenna design and placement is becoming relevant for GNSS receiver performance, added to production difficulties, for which a more robust European production industry is essential to support space needs. To this end, publication of service evolution roadmaps would support development and production planning, whilst fostering consistent implementation across space platforms to harmonise the requirements baseline demanded for different space missions.

From the SST perspective, the user needs are currently gathered through mechanisms within the EU SST capability. As regards to EO and SATCOM, no current use of its services or products by space users has been identified for the time being. However, EUSPA keeps monitoring the market to find new applications and opportunities for Copernicus data and services, and prospects for SATCOM are being explored (data relay systems, Lunar communications) in line with its mission of promoting and maximising the use of the EU Space Programme assets.

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1 SCOPE AND METHODOLOGY

1.1 Scope

The User Consultation

The User Consultation Platform (UCP) is a process developed at the European Union Agency for the Space Programme (EUSPA) to collect user needs and requirements and take them as inputs for the provision of user driven space data-based services by the EU Space Programme.

The objective of this report is to provide a reference for the EU Space Programme and for the Space segment community, reporting the most up-to-date user needs and requirements in the Space market segment for the use of Position, Navigation and Timing (PNT), Earth Observation (EO). Its scope is to cover needs and requirements from the user perspective, considering the market conditions, regulations, and standards that influence them. The report serves as a reference for end users, service providers and the whole EO community in planning and decision-making activities for those concerned. The report is also intended to serve as an input to more technical discussions on systems engineering and to shape the evolution of the European Union's satellite navigation systems, Galileo and EGNOS and the Earth Observation system, Copernicus, and in the future Space Situational Awareness.

The UCP process foresees a regular event, where users from different market segments meet to discuss their needs and application-level requirements relevant for PNT, EO and SATCOM and the conclusions are presented in this document. This report is a living and evolving document that is regularly updated by EUSPA. It served as a key input to the UCP, that is continuous process to reflect the evolution of the user needs, market and technology captured during the event. The report does not represent any commitment of the EU Space Programme to address or satisfy the listed needs and requirements in the current or future versions of the services and/or data delivered by its different components.

This report is organized as follows:

- Section 2.1 addresses the prospective use of EO/GNSS/SATCOM in the Space segment, with identified trends, and innovations
- Section 2.2 presents the market evolution and key trends in the Space segment, together with definitions of main user groups and actors in the value chain, followed by Section 2.3, that describes the market drivers (regulations, standards etc.)
- Section 2.4 describes applications and operational scenarios relevant for EO/GNSS/SATCOM, presenting main user needs and expectations towards services and data to serve operational scenarios, together with limitations and gaps identified by end users. Some applications are more detailed as they have been assessed specifically during the 2025 UCP.
- Section 2.5 summarizes the main User Requirements for the Space segment in the applications domains analysed in this report.

1.2 Methodology

The UCP process follows systematic steps that are implemented in a continuous, repetitive manner. The logical steps allow transparency and continuous updates of the results, considering the new market developments and evolving user needs and requirements.

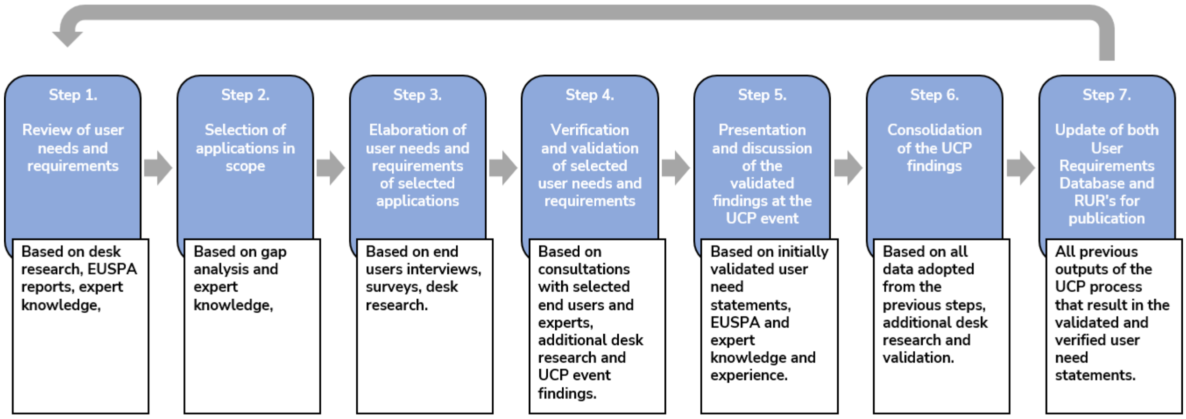

Figure 1: Space segment user requirements analysis methodology

Each Market Segment has its peculiar evolution due to the changes in legislation, standards, technological trends and so forth, therefore the update of the Report on User Need and Requirements can occur with a time distance of at least two years.

UCP user needs and requirements collection and analysis is based on one hand side on desk research and on the other, on stakeholders' consultations and experts' knowledge.

The UCP process starts with review and analysis of the most up-to-date sources related to the user needs and requirements in selected market segments. This step leverages on the previous UCP Reports on User Requirements, latest EUSPA EO and GNSS Market Report, Technology Reports and other expert publications and knowledge. The selection of relevant applications in each market segment is made based on the market analysis, the gap analysis from the earlier editions of the UCP and EUSPA, as well as external experts' know-how.

After the initial desk research, the stakeholders' consultations are carried out, both representing end users and intermediate users (service providers), in order to validate the findings and collect missing information (Step 3). Validation of user needs requires additional feedback from relevant users' representatives that review the draft version of the Report on User Needs and Requirements, prepared in advance of the UCP event.

The UCP event is organized by EUSPA on an annual basis and offers a forum to present and discuss the finding, being additional layer of updates and gaps filling in the process. All the information and data gathered during the previous steps are consolidated in the segment-specific, presented here Report on User Needs and Requirements (RUR) and later on in the EUSPA User Requirements Database (Step 7).

2 SPACE

2.1 The role of the European Space Programme to meet the evolving user needs

The role of EUSPA

EUSPA (European Union Agency for the Space Programme) plays a pivotal role in the context of the EU Space Programme, acting as a key operational agency that is user-oriented and focused on promoting and maximizing the uptake of satellite-based services across various sectors, through the following activities:

1. User-Centric Approach

- EUSPA adopts strategies that prioritize the needs and requirements of users. It aims to enhance the accessibility and integration of satellite services, ensuring that a broad spectrum of users, including governmental bodies, businesses, and citizens, can benefit from services related to Earth Observation, Satellite Navigation, and Connectivity.

2. Service Provisioning

EUSPA is responsible for providing state-of-the-art services in areas such as:

- Positioning, Navigation, and Timing: Through the Galileo and EGNOS systems.
- Satellite Communications: It facilitates communication services for governmental applications through GOVSATCOM and is working on the new IRIS2 initiative.
- Space Surveillance: EUSPA manages Front Desk services for the EU Space Surveillance and Tracking program, ensuring safety and security in space operations.

3. Enhancing the European Space Ecosystem

EUSPA works to foster a robust European space ecosystem by:

- Providing market intelligence and technical expertise to innovators, SMEs, and academia.
- Leveraging EU funding programs such as Horizon Europe to stimulate innovation and research in space-related technologies.
- Supporting startups and developing partnerships that enhance technological advancements.

4. Ensuring Security

- EUSPA plays a critical role in the security of the EU Space Programme. By operating the Galileo Security Monitoring Centre (GSMC), it implements and monitors the security of satellite services, thereby bolstering the overall security framework for EU Member States.

5. Stakeholder Engagement

- EUSPA actively engages stakeholders from the entire space value chain, including industry leaders, academic institutions, and end-users. It facilitates feedback mechanisms where users can express their needs and satisfaction levels regarding EU satellite services. This engagement is crucial for the continuous evolution of the EU Space Programme.

EUSPA conducts various essential activities which include:

- User Consultation Processes: These are designed to gather insights and perceptions from users to improve service delivery.

- Market and Technology Monitoring: EUSPA analyses trends and forecasts in the space industry to inform strategic decisions.
- Research and Development Funding: The agency identifies funding needs for R&D initiatives and ensures their implementation.
- Pilot Programs: EUSPA supports the testing and piloting of innovative applications to explore new possibilities in space services.
- Commercial Acceleration Programs: Through the CASSINI Programme, EUSPA promotes innovative commercial ideas and facilitates their growth in the marketplace.

In summary, EUSPA serves as a cornerstone of the EU Space Programme, bridging the gap between technological advancements and user needs. By providing innovative satellite services, fostering a collaborative space ecosystem, ensuring security, and engaging with a wide array of stakeholders, EUSPA is crucial in advancing the EU's strategic interests in space and enhancing the overall benefit of space technologies for society.

The role of European Global Navigation Satellite System (EGNSS)

EGNSS is the European satellite navigation program designed to provide highly accurate and reliable positioning, navigation, and timing services on a global scale and ensuring Europe's technological autonomy. EGNSS offers high-precision and multi-constellation capability. There is a free positioning service available to the public, as well as encrypted services for government and commercial use, like the Public Regulated Service (PRS) for government-authorized users. EGNSS includes two main systems:

- **Galileo** is the European satellite navigation system that provides highly accurate global positioning and timing information. It offers several unique features, including higher accuracy (especially in urban areas), improved availability, and an authentication service to prevent signal spoofing. Numerous EU economic sectors rely on Galileo, from transport and agriculture to border management and search and rescue. Its 20cm accuracy makes Galileo a game changer for autonomous driving and commercial drones. Already more than 3.5 billion smartphones are Galileo-enabled.
- **EGNOS** (European Geostationary Navigation Overlay Service) is a satellite-based augmentation system (SBAS) that improves the accuracy, integrity, and reliability of the navigation services to aviation, maritime and land-based users in over 30+ countries.

For the Space segment, Galileo provides precise and resilient Positioning, Navigation, and Timing (PNT) services that are essential for a wide range of space activities, including satellite operations, orbit determination, constellation management, and space situational awareness. Galileo high accuracy, signal robustness, and authentication capabilities enhance the reliability and safety of space missions, while contributing to European autonomy in space-based navigation and timing services.

Hereafter are the major takeaways from UCP 2025:

- The community continue to show a strong interest in GNSS applications in Space, particularly discussing user needs, requirements and use cases for the following applications:
    - GNSS-Reflectometry is a mature application taking advantage of spaceborne dedicated receivers targeting accuracy of 2–5 cm (mainly for altimetry applications), 99.9% availability.
    - Space-Based monitoring of space assets targets accuracies of <1 m, 99% availability, multi-frequency multi-constellation capabilities, and less stringent timing accuracy (milliseconds).
    - GNSS adoption for launchers has to reach an accuracy of <10m for Ascent and ~1 m for stage recovery/orbit injection, with full integration with inertial systems. New

trends of First Stage Recovery and Autonomous Termination Systems will consider GNSS an enabler, whilst Robustness and integrity parameters may need further definition work.

- The recent lunar mission LuGRE was also particularly of interest, with successful GNSS test results (Galileo and GPS signals successfully acquired for the first time in History, both during transit through cislunar space and on the lunar surface, with a 3D POD Position Error < 200 m and <1km respectively), demonstrating the future use of GNSS in deep space missions. Galileo services were tested and positive results were obtained, with also successful acquisition of OSNMA and EWSS messages.
- Galileo differentiators are enabling the use of GNSS in Space: HAS is supporting more demanding applications (e.g. Precise Orbit Determination), OSNMA is seen as an important service providing security, especially with interference cases raising in LEO, and EWSS tests in the Moon demonstrating that the service can be used to support deep space missions.
- Special attention was given to raising challenges, including the progress on antenna characteristics for onboard space assets and to strengthen the EU-based manufacturing capacity to meet European demands. The discussion also highlighted the increased need of opportunities for in-orbit testing and validation, clear service evolution roadmaps and manufacturer guidelines, and the importance of addressing standardisation aspects for future GNSS space applications,

Takeaways for GNSS from the 2025 UCP

The role of COPERNICUS

Copernicus is the Earth Observation component of the European Union's space programme, looking at our planet to support the management of the environment, mitigate the effects of climate change and ensure safety and civil security across Europe. Copernicus delivers its data and services with a free and open policy. It consists of three main components:

Space Component, which delivers data from a fleet of dedicated observation satellites (the 'Sentinels') and other Copernicus Contribution Missions (CCM). Six Sentinel satellites families are designed to serve a wide range of users and are provided with a free and open access globally. They ensure an independent and autonomous Earth Observation capacity for Europe with global coverage. The satellites provide observations which serve a wide range of users for a multitude of applications in the areas of climate, land and ocean services, emergency management, atmosphere and air quality, among others.

- Sentinel-1A provides all-weather, day and night radar imagery for land and ocean services. Sentinel 1-B was retired in December 2021. The Sentinel-1C satellite was launched on 5 December 2024 and Sentinel-1D on 4 November 2025.
- Sentinel-2A & -2B provide optical imagery for land and emergency services.
- Sentinel-3A & -3B provide optical, radar and altimetry data for marine and land services.
- Sentinel-5P provides atmospheric data, bridging the gap between ENVISAT and future Sentinel-5 data.
- Sentinel-4 & Sentinel-5 will fly aboard EUMETSAT MTG-S and Metop-SG satellites. They will monitor air quality, trace gases and aerosols over Europe at high spatial resolution and very high frequency.
- Sentinel-6 provides radar data to measure global sea surface height observations for climate monitoring and ocean and seasonal forecasts. It continues a time series of mean sea level rise measurements dating back to 1992. It is joint by its twin Sentinel-6B launched on 17 November 2025.

CCMs complement the data portfolio in the Sentinel satellites missions with another layer of value to meet user needs, providing data from commercial data providers. There are around 30 existing or planned to contribute missions, encompassing various technologies like SAR, optical sensors, spectrometers and altimetry systems.

In-Situ Component collects data acquired by a multitude of sensors at air-, sea- and ground-level, and includes geospatial reference data.

Service Component of Copernicus programme transforms the various data into timely and actionable information products. The Copernicus Services deliver value-added information products in six thematic areas:

Atmosphere Monitoring Service (CAMS)	Climate Change Service (C3S)	Emergency Management Service (CEMS)	Land Monitoring Service (CLMS)	Marine Environment Monitoring Service (CMEMS)	Security Service (CSS)

Figure 2: Copernicus services

However, as regards EO in the Space market segment, no current use of its services or products by space users has been identified for the time being. Nevertheless, EUSPA will keep monitoring the market to find new applications and opportunities for users. in line with its mission of promoting and maximising the use of Copernicus data and services.

European Secure SATCOM

The EU Secure Satellite Communication System, known as **GOVSATCOM** is an investment made by the EU, which aims to provide secure and cost-efficient communication capabilities to security and safety-critical missions and operations. **IRIS², the** new multi-orbital constellation of 290 satellites will provide secure connectivity services to the EU and its Member States as well as broadband connectivity for governmental authorities, private companies and European citizens, while ensuring high-speed internet broadband to cope with connectivity dead zones**.** The program is part of the EU's broader strategy to strengthen its autonomy, security, and defence capabilities, especially in response to increasing geopolitical challenges and cybersecurity threats.

The case of SATCOM is facing a similar situation as EO, where no applications have been yet identified. However, prospects for using SATCOM to support communication with Space users (e.g. a high-orbit satellite used as a rely of communications for lower-orbit satellites; or SATCOM in support to Lunar missions) exist and this will be monitored by EUSPA.

2.2 Market overview & trends

2.2.1 Market Evolution and Key Trends

Introduction to the Space market segment

GNSS has proven to be a very valuable tool in space since the first experiments with a spaceborne GNSS receivers took place very early during the deployment of the GPS constellation, and more concretely in 1982, when the first spaceborne GNSS receiver was deployed in Landsat-4, a Low Earth Orbit (LEO) satellite providing satellite imagery.

Since then, the space environment has hosted an increasing number of platforms and has become a new playground for GNSS technologies. Nowadays, the use of spaceborne GNSS receivers for real time spacecraft navigation has become a common technique in LEO, where the vast majority of satellites carry GNSS receivers to calculate their position. Spacecraft's attitude determination and timing applications have found their way as well in those cases where GNSS is part of the Guidance, Navigation and Control (GNC) subsystem, indispensable for the effective functioning of a satellite providing the means for the satellite to navigate through space, remain aligned with its mission objectives, and adapt to real-time challenges.

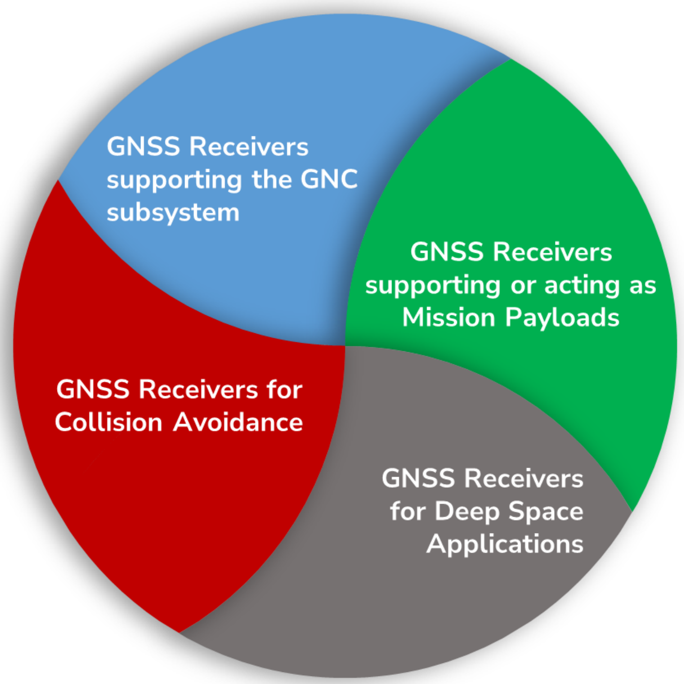

Figure 3: Space GNSS applications sub-segments

To be noted that the number of applications where **GNSS acts as mission payload** is increasing and that it is a further demonstration that Space segment has found many applications where GNSS signals can be used beyond PNT purposes, even becoming one of the spacecraft main scientific instruments.

Above LEO, the **Multi-GNSS Space Service Volume (SSV)** [RD3] enabled GNSS PNT applications to be extended to the Moon, contributing to the so-called Cislunar economy, as explained in EUSPA's EO and GNSS Market Report [RD1].

There is an additional aspect concerning the GNSS Space market supporting the positive trend foreseen for the following years. This is related to leveraging **applications exploiting synergies between SST and GNSS** as example which are starting to flourish. These are SST applications, mainly related to collision avoidance operations, where a clear enhancement is obtained when GNSS systems are used.

Key Market Trends

Advances in technology, increased private sector investment, and rising demand for space data are reshaping the space sector:

- **Advances in Technology**: the space sector has witnessed significant growth due to advancements in technology. Innovations such as reusable launch vehicles, SmallSats (low-mass satellites), and CubeSats (miniaturized square-shaped satellites) have driven down costs and expanded opportunities for space exploration. These developments enable more efficient manufacturing, launching, and operation of space-based assets.
- **Increased Private Sector Investment**: private companies are increasingly investing in space-related ventures. This surge in private sector funding has fuelled research, development, and commercialization of space technologies. As a result, new players are entering the market, contributing to its transformation.
- **Rising Demand for Space Data**: the demand for space data and related products and services continues on the rise. Satellites provide critical information for various applications, including weather forecasting, communication, navigation, and Earth observation. As more industries recognize the value of space data, opportunities for growth continue to expand.

In summary, the space economy is experiencing exponential growth, with continuous record rocket launches and a dynamic ecosystem of players. By embracing innovation, collaboration, and responsible practices, the space industry can capitalize on both short-term and long-term revenue opportunities. In addition, the space economy is leaving an entrepreneurial spirit, that have led to a significant reduction in costs and resulted in the provision of new products and services that have broadened the existing space user community.

As major trends:

- **LEO mega-constellation** projects have become a symbol of this new era. Driven by SATCOM needs about global coverage and low latency, **thousands of satellites**[1] are being launched to compete with large GEO satellites.
- The renewed **interest for Moon exploration** continues to be supported by more frequent missions, combining public and private companies, aiming to establish a permanent lunar activity.
- **Space-based Earth Observation services are growing** and consolidating thanks to emerging space-based sensing and tracking techniques derived from the multi-constellation, multi-frequency capabilities in spaceborne GNSS receivers, improving data quality and processed data.
- **Space is nowadays a critical domain for national security**, and so governments are investing in increasing resilience and autonomy, particularly through Space Situational Awareness and secured communications, as EU demonstrate with the GOVSATCOM and IRIS[2] initiatives.

Ultimately, in all of New Space missions' initiatives GNSS provides financial and technical benefits (reduction in the number of instruments, reduced dependence on ground-based stations and improved navigation performances) and therefore has become a must-have technology.

GNSS Market Evolution

Most of the new small LEO satellites need GNSS receivers onboard and because the LEO satellite constellations have a high replacement rate due their relatively short lifetime, these satellites stand as the key driver of the spaceborne receivers' market. Indeed, forecasted shipments of GNSS devices for Space over the following decade are estimated to grow up to 3,600/year by 2034. Consequently, the

[1] It is estimated that 4,500 new satellites are to be launched each year over the next decade.

installed base of GNSS devices will grow from around 5,000 in 2024 to more than 20,000 by 2034, where the majority of them will correspond to the 'Low-end' category (robust multi-constellation and multi-frequency devices) installed onboard mega constellations' satellites.

The 'Low-end' receivers, encompassing Commercial-Off-The-Shelf (COTS) technologies and low-cost products offering appreciable trade-offs between performances and affordability, and the 'Scientific' receivers, used as part of the payload instrumentation and responding to specific needs not necessarily navigation-related, will drive the market. Meanwhile, 'High-end' receivers will still be the baseline for higher orbits and long-duration missions, due to inherent reliability requirements.

The expected revenues generated by spaceborne GNSS receivers' sales (see Figure 4), are expected to follow the same continuous growing trend. Indeed, the revenue from GNSS device sales is forecasted to peak around 2034, where the revenue may become steady as the installed base of GNSS devices will no longer be able to compensate the decrease of unit prices expected in space GNSS receivers.

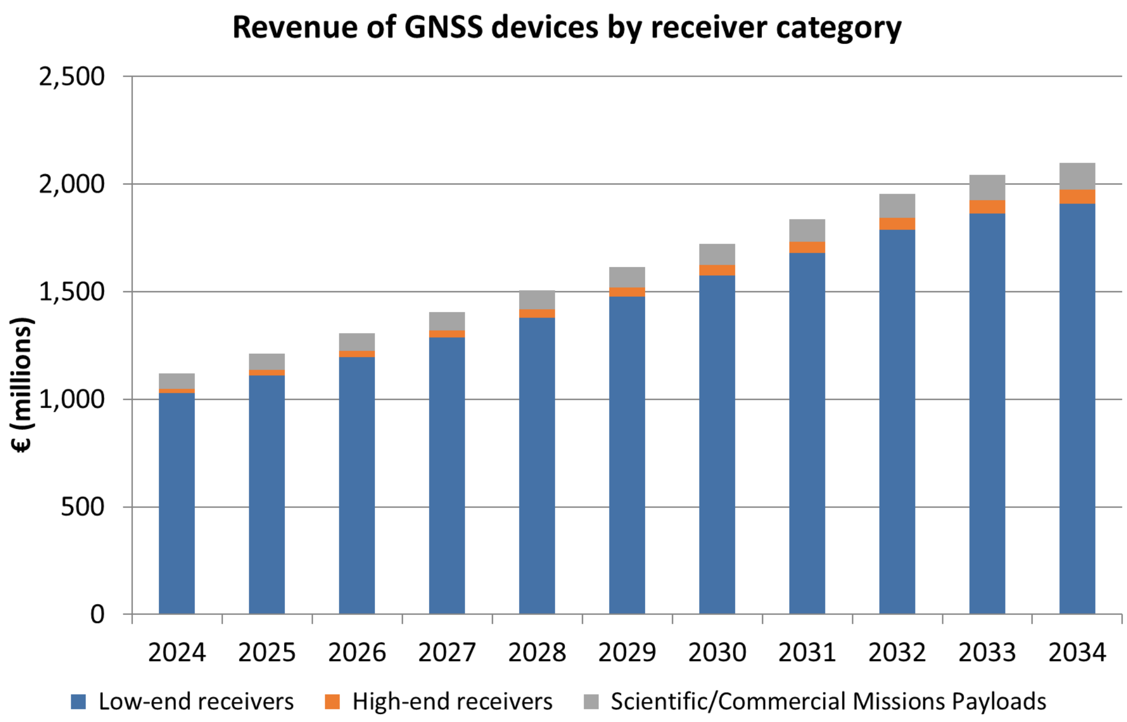

Figure 4: Forecast of revenue of spaceborne GNSS devices by receiver category

The biggest market is foreseen to be North America in the next 10 years, with more than 90% of the market (i.e. revenues from GNSS devices installed on-board North American spacecraft).

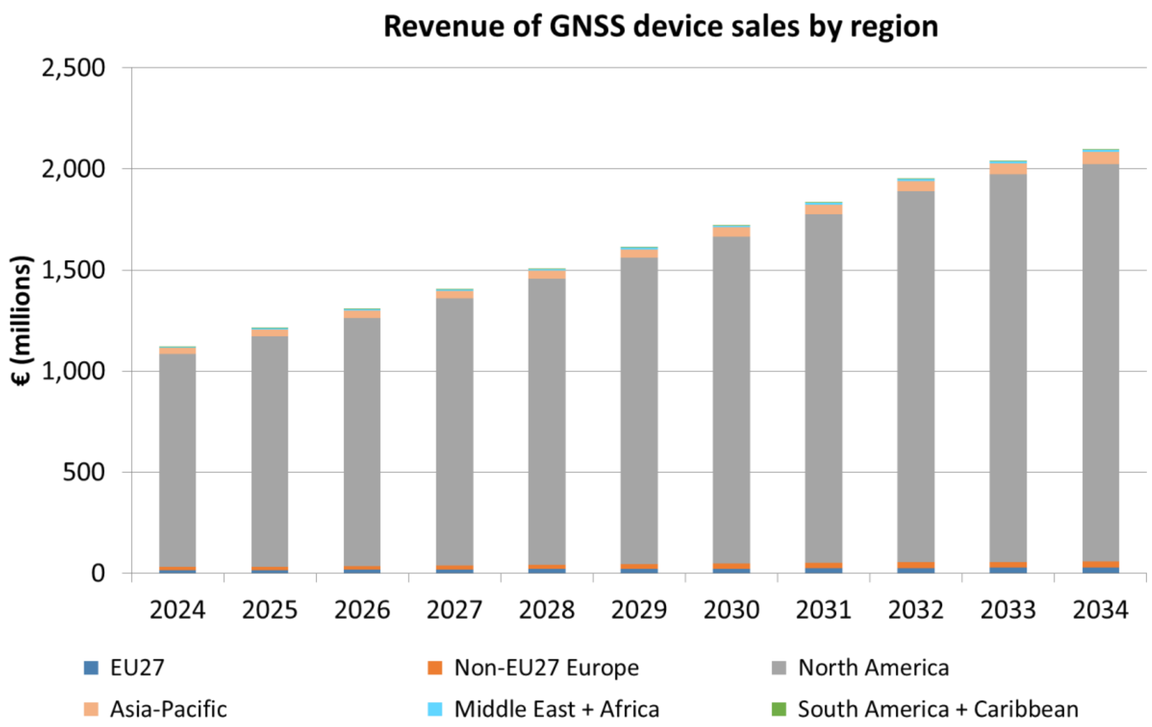

Figure 5: Forecast of revenue of GNSS by region

SST Market Evolution

The SST market grows driven by the rising number of satellites in orbit, New Space actors and the excessive cluttering of space debris.

Firstly, the economic aspects of space are changing in the New Space era, and the consequence is a strong increase in the number of satellites in orbit, notably with the deployment of the mega constellations. This increases the complexity of space operations and makes it impossible to safely operate a spacecraft without taking into account other spacecraft.

Secondly, the rise in number of satellites and space traffic activity increases the volume of debris generated and the risk of collisions. Already today, there are around 140 million pieces of debris smaller than 1cm orbiting Earth, and approximately 1.2 million pieces between 1 and 10cm. The current count of large debris (defined as 10cm or larger) is 54,000.

In addition, systems being developed are not only conceived for SST purposes, but also with a vision of Space Traffic Management (STM) [see [RD4], [RD5], [RD6] and [RD12]].

In parallel, there is a trend towards the commercialization of SST services, with the appearance of many different companies providing services based on their own sensor networks, space assets or on their own software infrastructure provided as a service, as a complement to the developments carried out on the institutional side. Two clear examples are the EUSST system, which is now ingesting commercial sensor data from EU providers, and the US TraCSS system, which is also being developed to ingest commercial sensor data from US providers mainly.

In conclusion. SST systems are an asset playing a relevant role in the value chain of Space Economy. According to a study conducted by Euroconsult [RD7], the SST commercial market in 2019 was estimated to total US$23,9 million and forecasted to grow to approximately US$125.7 million by the end of 2035.

2.2.2 Main User Communities and Market Players

Although the type of missions in which space users are involved is very diverse, the main user communities involved in the user requirement definition process for spaceborne GNSS receivers can easily be identified as entire categories along the value chain. The target groups that are key to facilitate the development and increased use of the GNSS in Space are therefore as follows:

- **Spacecraft integrators**. The role of the spacecraft integrators is to implement the navigation function in the overall system. The expertise of the integrator is usually positioned at the overall system level and not at the PNT function one. Yet, their knowledge of the final spacecraft mission(s) and the expected use of GNSS aboard is extremely valuable to define the navigation system performance and functional requirements. They are also well-equipped to understand and take into account the specific constraints raised by the space environment.
- **Spacecraft operators**, with a very practical view on how GNSS is used aboard the spacecrafts they are responsible of. As described in Chapter 2.4, one of the main uses of GNSS within spacecraft is to take part into the guidance, navigation and control (GNC) system – which is one aspect of spacecraft operators' tasks. They therefore have a good knowledge of the expected performances of the embedded GNSS spaceborne receivers.
- **Scientific & EO applications communities**. Beyond their interest for navigation and control purposes, GNSS data can be used by space users directly for the mission needs. This is in particular the case for scientists or Earth Observation (EO) professionals, from whom GNSS signals behaviour can be used to derive environmental parameters. Having different needs than classical GNSS users, their involvement in the definition of requirements for spaceborne GNSS receivers is essential.
- **Receivers' manufacturers**. Although spaceborne GNSS receivers' manufacturers are not direct users of their own products, their role in the definition and the prioritisation of the user's requirements remains important. Their ability to understand the users' functional and performance needs, as well as their knowledge of the potential design and development constraints raised by the space environment, allow to bring insightful information into the definition of these requirements. These actors are in particular deciding on the implementation and use of the Galileo Signals in their products.

Within SST, the following are the main Space user communities identified within this market segment:

- **Satellite operators**, whose assets can largely benefit from the use of SST systems and services for the operation of their satellites in various manners, as described in this report, during various phases of the satellite lifetime (Launch and Early Orbit Phase operations, end-of-life operations, etc).
- **Satellite mission designers**, who need information derived from SST in order to design the mission, both from an orbital point of view but also from the structural point of view.
- **In-orbit service providers**, who can benefit from the information obtained by SST systems on the assets to be serviced with their missions.
- **Governmental institutions**, who need to monitor the evolution of the population of objects around the Earth, and also the compliance against regulations and best practices.

Space-borne GNSS Value Chain

The main stakeholders involved in the spaceborne GNSS market are depicted in the value chain[2] below:

[2] The value chain considers the key global and European companies involved in GNSS downstream activities.

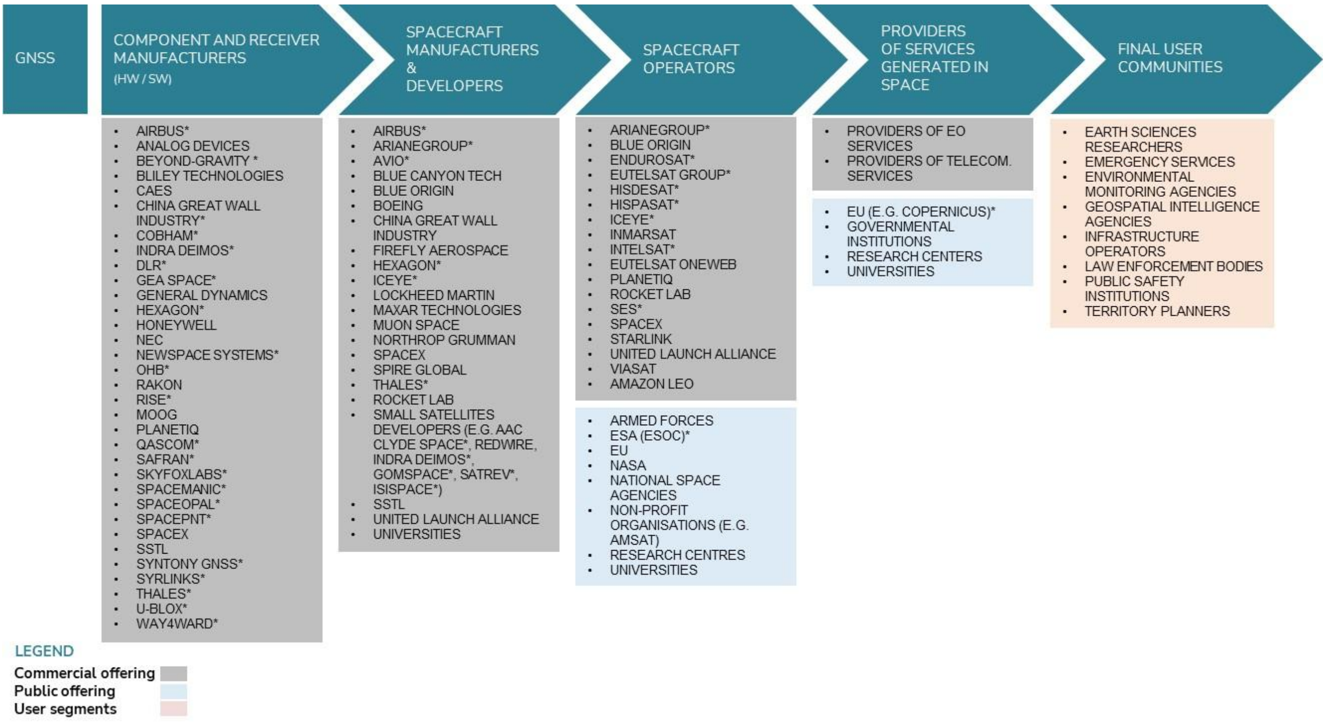

Figure 6: The GNSS value chain in the Space segment

To be noted that contrary to the value chain of other market segments, the value chain of the Space Users does not make any difference between module/chipset manufacturers and receiver manufacturers. Indeed, it is assumed that the high environmental constraints to be considered (e.g. high dynamics, use of radiation hardened integrated circuits, etc.) force receivers' manufacturers to develop their own chipsets.

The role of the key players is as follows.

- **Component and receiver manufacturers** include all the companies involved in the development and the production of GNSS receivers' for space applications, as well as the integration of GNSS chipsets on a board or within a device to address particular user requirements. These range from important and historical stakeholders whose receivers have long space heritages, as well as new entrants offering cheaper and lighter products, in particular for LEO applications.
- **Spacecraft manufacturers and developers** includes mainly private but also public entities involved in the design and the production of satellites. This part of the value chain also gathers historical and new actors, developing a wide variety of spacecrafts (e.g. for public, commercial or military usages, from a few kg SmallSats to several tons GEO satellites, etc.). The easier access to space, coupled to the explosion in demand for connectivity and other services, is all set to revolutionise the satellite and launchers manufacturing industry.
- **Spacecraft operators** are essential to the success of any space mission. From launching the spacecraft to ensuring that it is running correctly, they efficiently diagnose and solving any problems that occur. They operate space assets and sell bandwidth capacity or data for various applications.
- **Providers of services generated in Space** consists in the downstream part of the satellite industry value chain that generates the most revenues, addressing directly the end-users. A lot of companies are gathered into this branch of the market (in the figure, shown within the private companies' box), ranging from well-established service providers (mainly in telecommunications) to small start-up companies addressing niche market segments. The market structure is very scattered, in particular among the geo-information services providers.

- **Final user communities** consist in all the potential users of the space-based services made possible by the above-mentioned categories. The entire industry works towards serving these communities requirements and demands.

NOTE: A static picture of a dynamic ecosystem

As in previous editions of this document, it is essential to highlight that the value chain represented in Figure 6 only provides a static picture of an industry which has never been as dynamic as nowadays.

While historical stakeholders have been well-established in the value chain for a long time, the last decade has seen a significant number of actors entering the market. The New Space actors are not expected to replace historical ones, but rather to challenge and complement them. The technological push that has always defined the space industry is now strengthened by the user pull generated by new stakeholders' arrival and the needs they create.

The next decade is expected to continue witnessing the arrival of new players, the success/failure of some actors and the necessary adaptation of older stakeholders.

2.3 Market drivers: Policies, Regulations, Standards

This chapter describes regulations and policies that are relevant to the Space segment and may influence the uptake of the EU Space Programme by Space users.

2.3.1 Applicable regulations, treaties and conventions

A significant number of space-related international activities and agreements have been achieved under the auspices of the United Nations (UN). In the context of this document, the most relevant one is the **1967 Outer Space Treaty**, entering into force in October 1967, and which is commonly labelled the "Space Law" [RD8].

The treaty is based on the principle that **outer space is an area not subject to any territorial sovereignty**, where the freedom of use and exploration is the baseline legal principle. The treaty therefore consists on a body of rules addressing space activities: the freedom of use and exploration for the benefit of all mankind, the responsibility of states for national activities in outer space, the liability of states for physical damage caused by space objects, the registration of space objects by states involved in their launching or the mitigation of space debris.

However, the treaty does not constitute a proper legal framework for the use of any specific technologies in space – GNSS in this particular case.

To promote its position as a leader in space, the EU keeps devoting significant efforts in providing the sector and its industry with the necessary legislative and regulatory tools. Amongst these, the following are worth to mention:

- **Galileo 2nd Generation (G2G) Implementing Act**. In its 2nd Generation, Galileo will provide a Service for Space users, formalized through the corresponding Commission Implementing Decision [RD9].
- **The 'Space Regulation' establishes the Union Space Programme** and the European Union Agency for the Space Programme (EUSPA). The regulation establishes Galileo, EGNOS, Copernicus, SSA and GOVSATCOM as the components of the program [RD10].
- A new regulation is currently under discussion at EU level which is expected to introduce a harmonised framework for space activities within the EU. The initiative aims to address safety, resilience and sustainability aspects, which may have direct implications for spaceborne GNSS applications and related user requirements.

It must be noted that the 'Space Regulation' recognises in its preamble that "*GOVSATCOM is a user-centric programme with a strong security dimension*" and that "*The GOVSATCOM use-cases should be able to be analysed (...) for (...) key infrastructures, (...) such as (...) space infrastructures*".

Within Space Traffic Management (STM), for which EU Space Surveillance and Tracking (EU SST) would constitute its operational capability at EU level, there is nowadays no international treaty or regulation covering all space-related stakeholders to address space traffic concerns. The existing regulations do not provide ruling on the interactions and coordination between space traffic actors, although several non-regulatory activities are already in place at EU and international level (as detailed in section 2.3.2). With the increase of the objects in space, the need for space actors to reach an agreement on a set of rules related to STM becomes mandatory.

2.3.2 Non-regulatory sources

GNSS

The **Interoperable Global Navigation Satellite Systems Space Service Volume (2021)** [RD3] is a booklet published under the auspices of the United Nations International Committee on GNSS (ICG), with the objectives of "*defining, establishing and promoting an interoperable GNSS SSV [Space Service Volume] for the benefit of GNSS space users and GNSS space receiver manufacturers*". The document is built on the basis that interoperability between GNSS systems offers tangible benefits for Space GNSS users, who operate in an environment significantly different than the environment of a classical terrestrial receiver in terms of pseudorange accuracy, received signal power and signal availability.

The document is the result of contributions from each GNSS service provider and constitutes a single resource where the characteristics provided by every GNSS are concisely offered for the development of new GNSS-applications in Space.

At EU-level, again it is worth to mention several reference documentation setting EU's vision and strategy on Space-related matters:

- The **Space Strategy for Europe from 2016** [RD11]. The international space context was evolving rapidly, with competition growing, space activities becoming increasingly commercial and a greater private sector involvement. With major technological shifts challenging traditional models in the sector but also bringing significant opportunities for all EU countries, the space strategy for Europe was launched to:
    - bring tangible benefits to European citizens and companies;
    - foster a competitive and innovative European space sector;
    - reinforce the EU's strategic autonomy; and
    - strengthen the EU's leadership on the global stage.
- **10th EU/ESA Space Council 2020.** The 10th high-level EU/ESA Space Council took place on Friday 20 November 2020 with the objective to adopt "Orientations on the European contribution in establishing key principles for the global space economy" – emphasizing the precepts set-out earlier in the Space Strategy for Europe and highlighting the potential for the spaceborne EGNSS market.

SST and STM

A few <u>non-regulatory activities on STM</u> have already been initiated by many bodies and organisations.

Many of these entities have already proposed a code of conduct for STM; and indeed, many international organisations are providing their recommendations to the national regulators in the form of guidelines.

At EU-level, a significant initiative to ensure the security, safety and sustainability of space operations is the **EU approach to Space Traffic Management** from 2022 [RD12], proposed by the Commission and the High Representative of the Union for Foreign Affairs and Security Policy (HR/VP). It calls for an EU contribution to STM along four key lines of action:

- Assessing STM requirements and impacts for the EU;
- Enhancing operational EU SST capabilities to support STM;
- Fostering STM regulatory aspects;
- Promoting the EU STM approach at a global level.

Beyond EU, quite a number of guidelines and rules have been defined to ensure the security, safety, sustainability and stability of space operations in the recent years. Amongst them, the following must be particularly highlighted:

- The Net Zero Space Initiative, a global platform gathering +65 actors to raise awareness on the pressing need to better protect Earth's orbital environment (2021).
- The ESA Space Debris Mitigation Policy for Agency Projects, ESA/ADMIN/IPOL(2014)2 (2014).
- The European Code of Conduct signed by ASI, UKSA, CNES, DLR and ESA, (2006).
- The Space Debris Mitigation Guidelines from UN COPOUS (2009) emerging from its Long-term Sustainability of Space Activities (updated in 2018).
- The IADC Space Debris Mitigation Guidelines, IADC-02-01 Rev.2 (2020).
- The NASA Process for Limiting Orbital Debris, 8719.14A (2012).
- The NASA Procedural Requirements for Limiting Orbital Debris, NPR 8715.6B (2017).
- The NASA Handbook for Limiting Orbital Debris, NASA-HDBK-8719.14 (2008).
- The U.S. Government Orbital Debris Mitigation Standard Practices, (updated in 2019).
- The Technical Regulations of the French Space Operations Act (2008).
- The 2011 ISO standard 24113 on debris mitigation requirements.
- The Best Practices for the Sustainability of Space Operations issued by the Space Safety Coalition (https://spacesafety.org/) (2019), endorsed by the main space industry stakeholders
- The Policy brief from the EPFL International Risk Governance Center (IRGC), Policy options to address collision risk from space debris, and the policy report, Collision risk from space debris: Current status, challenges and response strategies.

GOVSATCOM

Due to its capacity to provide guaranteed and secure communications, GOVSATCOM will be able to support the management and operation of key space infrastructures like Galileo and Copernicus[3]. In particular, GOVSATCOM could serve two different purposes: to distribute services to governmental end-users and to ensure information exchange within the infrastructure itself.

EUSPA Secure SATCOM Market and User Technology Report [RD13] provides an overview of the cases where GOVSATCOM can support the operation of the Copernicus, Galileo & EGNOS and SST systems' infrastructures and/or the provision and evolution of the services provided by each component.

[3] https://defence-industry-space.ec.europa.eu/govsatcom/

2.4 User Needs and Requirements

This chapter provides a detailed analysis of user needs and requirements pertaining to Space applications introduced before, describing the different roles and needs covered by GNSS, EO and SATCOM, and, ultimately, identifying the corresponding requirements from a user perspective.

In this segment, the role or functions of the embedded GNSS receiver varies, depending on the spacecraft's mission. While they can be used as a guidance and navigation control (GNC) subsystem (i.e. for precise orbit determination, attitude determination or synchronisation purposes), they can also be used as one of the payloads serving directly the mission objectives (e.g. radio occultation measurements). The use of GNSS for navigation purposes in Cislunar space (e.g. on a translunar trajectory) is also relevant.

During the UCP 2025 [RD2] no Space applications benefitting from EO or SATCOM products and/or services were discussed due to the very limited applicability[4]. For this reason, the current version of this Report on Space User Needs and Requirements does not address EO-or SATCOM user needs. Nevertheless, these remain in the scope of the Report and will be included in future releases as soon as applications will be identified.

On the other hand, this document does still not include SST requirements, even if related applications are now covered. Attention has been paid to identify applications where both the GNSS and SST components are used.

Therefore, Table 1 below depicts the main applications making use of GNSS and/or SST technologies in Space. The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report being the third version of the Space report on User Needs and Requirements relevant to SST in addition to GNSS, is a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or SST, the current issue of the RUR does not cover in detail the needs and requirements of all applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in this section:

● Application Type A: these applications correspond to those for which an in-depth investigation is presented and for which needs and requirements relevant to GNSS and SST have been identified and validated with Space user community at the UCP.

◑ Application Type B: these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

○ Application Type C: these applications correspond to SST-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

The table below maps the **Space**-related applications to the three above-mentioned types. Again, it is highlighted that no EO or SATCOM-based applications have been identified in this version of the report.

[4] Within this section, however, a few examples of EO satellites making use of GNSS receivers to accomplish their mission objectives are provided. Some of them have been essential to obtain GNSS requirements derived from EO missions.

The following list of applications and their categorisation are expected to evolve in the next versions of the document.

Legend

SST only application
GNSS only application
Hybrid/synergetic application (combined use of SST and GNSS)

Sub-segments	Applications	Types of Application/ Level of Investigation	
GNSS Receivers supporting the GNC subsystem	Real-Time Navigation	A	
	Precise Orbit Determination (POD)	A	
	Attitude Determination	A	
	Timing & Synchronisation	A	
GNSS Receivers supporting or acting as Mission Payloads	Geocoding	B	
	Time-stamping	B	
	Atmospheric Radio Occultation	A	
	Gravimetry	B	
	Reflectometry	A	
GNSS Receivers onboard launchers vehicles	Navigation in Launch and Ascend phases	B	
	Stage Recovery	B	
	Flight Termination Systems	C	
	Spaceport's ground transport vehicles	C	
GNSS Receivers for Deep Space Applications	Translunar Trajectory (i.e. Moon Transfer Orbit)	B	
	Moon Orbiting	B	
	Moon Surface positioning	B	
GNSS Receivers for Collision Avoidance	Autonomous Collision Avoidance	B	
	Late Collision Avoidance Manoeuvre command	B	
	Space corridors for Space Traffic Management (STM)	B	
	Trajectory broadcasting for STM using on-board GNSS receivers	B	
Space Operations Monitoring and Support	Launch and early operations phase	A	
	Space-Based Monitoring and Tracking	B	

Sub-segments	Applications	Types of Application/ Level of Investigation	
	Re-orbiting operations	C	○
	Rendezvous and proximity operations	C	○
	End-of-life operations	C	○

Table 1: Applications and level of investigation

2.4.1 GNSS receivers supporting the GNC subsystem

The Guidance, Navigation and Control (GNC) subsystem of an orbiting spacecraft is in charge of providing and controlling the orbit and the attitude. It is therefore mainly composed by two functions:

1. the **Determination** of specific parameter (e.g. orbit position, absolute and relative velocity, attitude, rotation/spin, etc.)
2. the **Control** of specific parameter (e.g. orbit characteristics, attitude/pointing direction, rotation/spin, etc...)

Different components can be embarked to feed the GNC and allow real-time position determination; these include reaction wheels, magnetic torquers, star trackers or inertial sensors, to name a few. A GNSS receiver can also become part of the GNC, and in particular of the Determination function, being a passive sensor.

2.4.1.1 Real-Time Navigation ●

Description of the application

Real-time navigation onboard orbiting vehicles such as satellites, which motion is mainly influenced by gravity of celestial bodies, is based on the use of orbit propagators. An orbit propagator is a model, a solver, that allows predicting the orbital characteristics of a satellite given the current orbital characteristics. In other words, because the forces acting on an orbiting spacecraft are known, its free movement is highly predictable; therefore, the model takes this information into account to constraint the estimated position of the vehicle and, in the end, provide a more robust and accurate positioning.

Real time navigation allows the spacecraft to self-determine its position, thus reducing dependence on ground-based stations and lowering mission operations costs. The availability of real-time information is also crucial when contingencies pop-up, for example to support quick recovery trajectories after rocket orbit injections.

On the other hand, the orbit determination of **geostationary satellites** has been traditionally based on ranging at two distantly located ground stations or on ranging and azimuth/elevation angle measurements at a single station.

In the first case, distances between the satellite and the so-called ‘ranging antennas’ are measured on the Earth at different times. These distances are determined by measuring the time needed for a radio signal to make the round trip between the ranging antenna and the spacecraft. This is not a very efficient process, as the spacecraft needs to be equipped with an atomic clock and is dependant and waits for commands to be received from the ground station instead of making real-time computations.

In the case of **space launchers**, with different phases and including the recovery of stages, the use of GNSS is emerging, as navigation has been traditionally based on inertial navigation systems (INSs). This is addressed specifically in section 2.4.3.

Technologies and role of GNSS

Thanks to its high performances and real-time capability, GNSS is an enabler of real-time navigation. In this case, consecutive GNSS observations are processed in a Kalman filter that combines the predicted state with new measurement information. As a recursive algorithm, the filter is updated with each new observation, and so new estimates of the spacecraft position are obtained.

The specifics of the algorithms will largely depend on the desired accuracy, but for applications where a m-level accuracy is enough, the use of a pseudorange-based single-point positioning (SPP) is typically used[5].

GNSS-based navigation improves the overall performance, **achieving meter-class accuracy and even less in some applications**. This enables new space flight methods such as precision formation flying, as will also be presented later on.

The equipage and use of GNSS receivers onboard new **LEO satellites** is nowadays the primary method for performing orbit determination, replacing ground-based tracking methods.

The use of GNSS onboard **geostationary satellites**, however, is not as extended as in the previous case, principally because these spacecrafts orbit the Earth at a higher altitude than GNSS satellites do. However, since a few years ago, GNSS is also finding its way here thanks to new receivers that receive spillover signals and side lobe signals from GNSS satellites.

Mostly used for satcom applications, this kind of spacecraft are placed into orbital slots where they must remain with a certain level of accuracy (the concept of station-keeping).

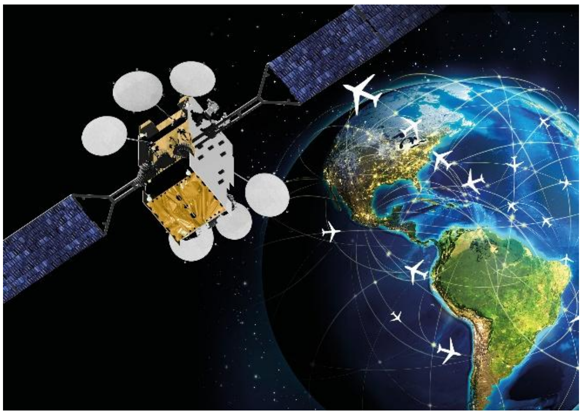

Figure 7: Render from SES-17 GEO satellite

In addition, their Geostationary Transfer Orbits (GTO) must be carefully calculated since, with the use of **electrical propulsion** thrusters, this can become a journey of dozens of days, if not hundreds.

Introduction to the corresponding user requirements

GNSS provides PVT information to **LEO satellites** that contributes to their **increased autonomy** [RD14]. Such increased autonomy allows, for example, to:

- Monitor the orbit of the satellite to compensate for orbit changes caused by a variety of natural perturbations. Orbital information with a position accuracy of 10–100m is generally adequate; or
- Support the attitude control of the spacecraft in EO missions, by providing information of the instantaneous position and velocity with accuracies of about 10m and 1–10 cm/s;
- Conduct autonomous operations related to the mission. For example, by activating any sort of sensing instrument upon reaching a pre-determined orbital position; thus, avoiding the dependence from ground-mission planning. Orbital information with an accuracy at the 10–1000m level will be required, depending on the application.

The following are examples of nowadays achievable performances in real-time:

- In a dual frequency configuration, typical LEO performances of the Airbus' LION Navigator are <1 m (RMS) position accuracy and <2 mm/s (RMS) velocity accuracy;

[5] Insights on applications making use of carrier-phase based precise point positioning (PPP) are provided within the *Precise Orbit Determination* application.

- The GPS-only receivers onboard Sentinel 3A&B provide real-time accuracies of 1-2 m (3D RMS) for position, and 2-3 mm/s (3D RMS) for velocity[6]. Improved performances are expected for the upcoming Sentinels 3C&D, embedding GPS + Galileo receivers.

The use of GNSS in **GEO satellites** provides many advantages: enhanced PVT, reduced operating costs due to less dependence on ground station facilities, and autonomous orbit navigation and control for both GTO and station keeping. In these spacecrafts and due to GTO and final orbit positioning, the number and orientation of antennas have to be selected considering varying attitude guidance requirements.

When it comes to station keeping, the ITU recommends maintaining the GEO's position within ± 0.1° of longitude (~4km to each side) of its nominal position irrespective of the cause of variation [RD15]. The accuracy of the station-keeping depends to some extent on the accuracy of orbit determination.

Actual performances reported by a telecom operator during UCP 2023 are 20-40m cross track and 5m radial (1σ) during station keeping, and 25-50m (1σ) in all directions during GTO, significantly improving the dual station tone ranging alternative. In all cases, these are reported as '*sufficient for orbit determination and manoeuvre calibration*'.

The geostationary GOES-R weather satellite, for example, has a position knowledge requirement during station keeping of 75m cross track, and 100m radial (3-sigma) [RD16], which following conversions proposed in [RD17], approaches the above reported performances.

Irrespectively of the specific contribution that orbit determination could have on the total error budget, receivers specifically designed for GEO satellites are already available in the market (e.g. from Beyond Gravity and from Airbus), confirming the results obtained during the last years by the scientific community: accuracies in GEO below 30m (two orders of magnitude below ITU's recommended maximum deviation) can be achieved.

However, other considerations must be taken into account as well. Space is a harsh environment and receivers must be built to last at least as much as the mission duration. Under severe radiation conditions, not only the design itself but also the selection of hardware components is different. For example, GEO satellites conceived to operate for 15 years carry electronics based on space-qualified parts. On the other side, minisatellites designed to orbit for only 2 years, or even less, could use avionics made of COTS parts (e.g. from automotive industry).

The high-dynamic of the platforms (vibrations during launch, accelerations…) also pose specific challenges. In addition, considerations of processor load (thermal management, power consumption) as well as software complexity and verification are part of the equation.

The following table presents the main GNSS user requirements for Real-Time Navigation. The definition of the key GNSS performance parameters can be found in Annex A.3.

[6] https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry/instrument/gnss

GNSS user requirements for Real-Time Navigation		
Accuracy	Narrowband communications in LEO (3D)	10-100 m (95%)
	Broadband communications in LEO (3D)	10 m (3σ)
	IoT communications in LEO (3D)	10 m (3σ)
	GEO Station keeping (2D, cross track)	75 m (3σ)
	GEO Station keeping (radial)	100 m (3σ)
	GEO Transfer Orbit (GTO)	150-600 m (3σ) 350 m (95%)
	EO: SAR[7] altimetry	10m (3σ)
	EO: Optical	10m (3σ)
Velocity accuracy	Narrowband communications in LEO	1–10 cm/s (RMS)
	Broadband communications in LEO	1–10 cm/s (RMS)
	IoT communications in LEO	0.03 m/s (RMS)
	GEO Station keeping	1 cm/s (RMS)
	EO: SAR (3D)	1–10 cm/s (RMS)
	EO: Optical (3D)	1–10 cm/s (RMS)
TTFaF	IoT communications in LEO	<5 minutes
	Other	<15 minutes
Service area	Geographical coverage	Global

Table 2: GNSS user requirements for Real-Time Navigation

2.4.1.2 Precise Orbit Determination (POD)

Description of the application

Precise Orbit Determination (POD) consists on the **estimation of the position and velocity vectors** of the orbiting spacecraft **with the highest possible accuracy**. POD is hance also based on the use of orbit propagators and on advanced numerical methods, but where input data, including errors characterization, is more accurate.

POD serves as the basis for several satellite applications, including science and navigation applications, and the **evolution of POD to achieve the best results in terms of orbital accuracy has been driven by mission requirements from, mostly, EO missions** in LEO: SAR, Altimetry, Radio Occultation, etc.

Thus, and because, traditionally, the latency of POD was not a big concern, POD has been performed on the ground, in post-processing, and making use of the best available auxiliary data. Products generated via Satellite Laser Ranging (SLR) technologies or provided by Doppler-based services such as the International Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) service (IDS) have been used to obtain precise orbits.

The orbit accuracy (3D RMS) achieved with the most advanced POD can be of 1 cm for the position (even below in directional components of interest e.g. radial component in altimetry missions), and typically between 0.1 mm/s to 1 mm/s for the velocity. As mentioned, though, this is achieved on ground in **post-processing.**

Therefore, and despite being in line with EO mission needs, the post-processing limitation might prevent its use for other applications that require **high accuracy in near/real-time**.

[7] Synthetic Aperture Radar

Technologies and role of GNSS

More recently, the **use of GNSS to determine POD has grown in importance and established itself as one of the common techniques to determine the trajectories of satellites in LEO** (the use of GNSS receivers supporting or acting as Mission Payloads is covered in next chapters). As already explained, in the case of Real-Time Navigation the use of a SPP technique is enough as part of the orbit determination function. However, in the case of POD, the concept of carrier-phase-based precise point positioning (PPP) comes into play, and corrections to various errors and delays (clocks, precise orbits, etc) must be available for the computation.

For non-real time POD, the use of high-quality dual-frequency GNSS receivers onboard the satellites, combined with the processing on the ground, provides the best accuracy that today can be achieved in GNSS POD (accuracy figures in line with the ones reported above).

For example, the **Sentinel-6 Michael Friedlich**[8] satellite is equipped, as main science payload, with a Poseidon-4 Synthetic Aperture Radar (SAR) altimeter. To get the most out of this sensor, the spacecraft makes use of a Precise Orbit Determination (POD) suite comprising GNSS receivers, with its antennas located on the roof of the satellite to optimise the receiving of signals from the Galileo and GPS constellations. The POD suite is completed with a Laser Retroreflector Array (LRA) and a DORIS system.

In addition, advances in numerical methods have increased the timeliness of information, reaching a point where reducing the latency of POD is constrained, in many cases, by the passing of the satellites over the tracking stations, when onboard GNSS observations can be downloaded and POD is hence conducted in a matter of hours if not minutes (i.e. near-real-time POD).

Finally, the case of more advanced operations such as Rendezvous & Docking or precision formation flying deserves a few words:

- **Rendezvous & Docking**: this refers to the case where two spacecraft conduct orbital maneuvering so as to meet in space with the same orbit and approach each other to a very close distance (rendezvous). Then, to docking can follow, where the two spacecraft join into a complex – which is a key operational technology for complicated space missions such as assembling a space station or repairing a satellite (e.g. Hubble telescope Service Missions between 1993 and 2009) in space. Indeed, the so-called **In-Orbit Servicing (IOS)** represents a change of paradigm, where in-orbit operations involving physical contact or very close proximity operations between a servicer and deployed spacecraft will open an entire new market for areas such as robotics, manufacturing and in-orbit operations.
- **Formation flying**: in this second case, widely separated spacecrafts (two or more) zipping through space at thousands of kilometres per hour work together to conduct their mission.

Usually, for Rendezvous applications, an absolute and highly accurate location of the spacecrafts is required until their baselines become sufficient short so as to accurately compute the relative location of the moving spacecrafts. With **GNSS-based relative navigation**, positioning algorithms can increase the relative positioning accuracy by an order of magnitude with respect to absolute navigation, consequently enabling automatic Docking applications. This can be achieved in real-time and requires proper synchronization of measurements taken onboard the individual satellites.

Introduction to the corresponding user requirements

It is difficult to establish requirements on POD, as per definition, the aim is to estimate the position and velocity vectors of the orbiting spacecraft "*with the highest possible accuracy*".

As an example, the absolute positioning accuracies achieved for Sentinel-3B (non-real time) are about 1.25 cm, 0.7 cm, and 0.5 cm with latencies of 30 min, 1.5 days, and 25 days, respectively.

Whatsoever, the space community keeps working on the development of real-time GNSS-based POD technologies, able to provide precise ephemeris and clock products for the GNSS satellites in real-time.

[8] https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-6/instrument-payload

In this sense, perhaps the most notorious advance in the last years has been the **availability of the Galileo's High-Accuracy Service (HAS)**, which broadcasts free-of-charge high-accuracy corrections (orbits, clocks, and signal biases) directly from its satellites via E6b frequency, and the development of spaceborne PPP receivers able to exploit it. The real-time orbit accuracy (3D RMS) reported by the first space GNSS HAS receivers available in the market is below 20cms for the position (in line with the service commitment) and below 1mm/s for the velocity[9].

In the case of formation flying, **relative navigation is often combined** with POD to achieve the primary mission goals, such as the one from ESA's TriHex [RD18]. In TriHex, composed of three complementary hexagon-shaped spacecraft in formation flying at 500km altitude, the relative position is continuously provided by a GNSS receiver connected to three antennas on each spacecraft, with measurements shared over a RF link. Real-time relative navigation achieves an accuracy of 1 cm.

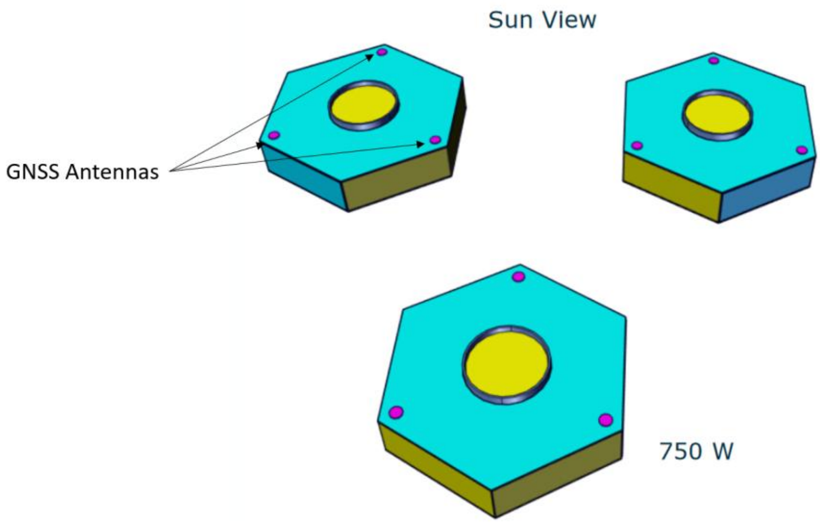

Figure 8: TriHex architecture, sun view (credits: ESA)

The following table presents the main GNSS user requirements for Precise Orbit Determination. The definition of the key GNSS performance parameters can be found in Annex A.3.

[9] See, for example, PODRIX receiver from Beyond Gravity https://www.beyondgravity.com/en/satellites/electronic-solutions/navigation-receivers

GNSS user requirements for Precise-Orbit Determination		
Accuracy	EO: SAR (3D)	0,6 m (95%)
	EO: Optical (3D)	0,6 m (95%)
	EO: Altimetry missions (radial)	2 cm (RMS)
	Rendezvous and Docking and Formation Flying	10-20 cm (3σ) 15 cm (95%)
	EO: Radio-Occultation (3D)	40 cm (95%) 5 cm (RMS)
Velocity accuracy	EO: SAR	1-10 mm/s (RMS)
	EO: Optical	1-10 mm/s (RMS)
	Rendezvous and Docking and Formation Flying	1-10 mm/s (RMS)
	EO: Radio-Occultation (along-track)	< 0.05mm/s (RMS)
Time To First Accurate Fix (TTFaF)		<15 minutes
Service area	Geographical coverage	Global

Table 3: GNSS user requirements for Precise-Orbit Determination

2.4.1.3 Attitude Determination

Description of the application

Spacecraft attitude determination consists on estimating the spatial orientation of a spacecraft, so that the Control function can actuate and make it point into some desired direction. In other words, being accurately aware of the vehicle's orientation in space allows to apply – if needed – the necessary torques to obtain the desired attitude. Indeed, a spacecraft's overall pointing error is a function of both the attitude determination errors and control errors.

Often, the success of space missions' rely on proper angular orientation of the spacecraft: it is necessary to support precise pointing and payloads' stability. For example: use of precise communication data link among satellites (e.g. formation flying), precise pointing direction of a camera to acquire images of a determined area on Earth, etc. It is also commonly (optimising sunlight incidence on solar panels) and proper thermal control.

It should be noted that attitude control and pointing stability are more challenging with smaller satellites than larger ones due to the difference in masses (inertia) of the platforms. CubeSats rotate easier in orbit and are more difficult to stabilise because they do not have as much inertia. Additionally, CubeSats' strict constraints on power consumption, mass and volume makes the development of a precise and accurate Attitude Determination System (ADS) very challenging.

Technologies and role of GNSS

Attitude determination has been based, traditionally, on the use of star trackers, sun sensors, horizon sensors, magnetometers and gyroscopes; and the development over the years has focused on greater levels of resolution and accuracy, and a decrease in size, weight and power requirements of the instruments.

Many spacecrafts nowadays determine their attitude in two modes: coarse and fine. The first one provides a 3D orientation in the order of degrees. The second one can reach, through star trackers, accuracies below hundredths of a degree.

The **Sentinel-6 Michael Friedlich** satellite is again a good example about how attitude determination systems play a key role in supporting the spacecraft mission. In this case, star trackers are used to determine the satellite's absolute attitude. It has three of these units pointing in different directions since in flight one or the other will be blinded by sunlight or moonlight at some point in an orbit. A Coarse Earth Sun Sensor supports the operation.

The use of GNSS (GPS-only by that time) for real time space-based attitude determination started with the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere/Shuttle Pallet Satellite (CRISTA-SPAS) missions, in 1994. And significant evolutions have occurred since then.

Attitude determination with GNSS can be conceived in 2 different ways: with 1 or with 3-4 antennas.

- When a 1 single antenna approach is used, the receiver compares the signal strength of the tracked GNSS satellite with the antenna radiation pattern and the resulting attitude is relevant only to the pointing direction of 1 axis (i.e. it is a 2D attitude information). In this way, only a rough orientation of the GNSS antenna with respect to the GNSS satellite is obtained. In addition, errors affecting power levels (such as multipath caused by the spacecraft itself) can severely affect the measure. Consequently, the achievable performance is reduced, in the order of tens of degrees.
- When 3 or 4 antennas are used, achievable performances are higher and attitude information is complete (i.e. 3D). In this arrangement, the attitude can be determined by measuring the relative positions of multiple GNSS antennas mounted on different noncollinear positions of the spacecraft. One of the factors influencing the performance of GNSS attitude determination systems is the relative distance between antennas (referred to as baselines). Usually, antennas are mounted so that the baselines are at least several integer cycles longer than the wavelength of the GNSS signal carrier (the use of carrier-phase measurements increases the accuracy of the system). This means that the size of the vehicle must support the long antenna baselines. In the end, sub degree accuracies for baselines of 1m are achieved, reducing to <0.1° when baselines are larger.

The International Space Station, for example, uses a combined GNSS (GPS) and Inertial Navigation System since 2002 for attitude determination that achieves the 0.5° error (3 sigma) mission requirement. Multipath effects caused by this particular spacecraft prevent achieving the requirement with a GPS-only solution. The antenna array consists of four antennas in a 3 x 1,5-meter rectangle.

TopSat was a low-cost EO mission between 2005 and 2010.

The GPS receiver mounted on the spacecraft was primarily used for orbit determination and on-board clock updates, but was suitable to also conduct attitude determination experiments.

For this purpose, four GNSS antennas were mounted on the space-facing (-Z) facet of the spacecraft (see Figure 9). The mission was able to demonstrate real-time GPS attitude determination on a microsatellite platform, accurate to the degree-level.

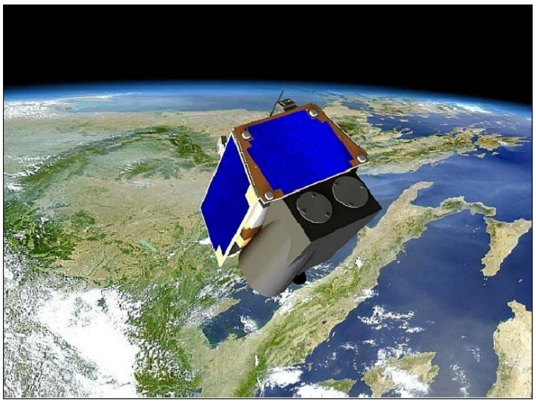

Figure 9: Artist's view of TopSat in Earth orbit (image credit: QinetiQ)

Introduction to the corresponding user requirements

Star trackers, sun sensors and horizon sensors provide better accuracies than GNSS attitude systems, which in any case become excellent back-up options. However, GNSS attitude systems provide other advantages, predominantly in terms of weight, maintenance and cost, and thus become excellent options for satellites which accuracy requirements are not so stringent. In addition, star trackers provide a very precise knowledge of the attitude with respect to the fixed stars (i.e. absolute attitude determination), but they still require complementary determination of Earth direction.

The following table presents the main GNSS user requirements for Real-Time Navigation. The definition of the key GNSS performance parameters can be found in Annex A.3.

GNSS user requirements for Attitude Determination		
Accuracy	In each axis	0.1° (3 sigma)
Service area	Geographical coverage	Global

Table 4: GNSS user requirements for Attitude Determination

2.4.1.4 Timing & Synchronization

Description of the application

The need for highly precise timing information is relevant in space both for timing and synchronisation. These two applications serve as core of data collection in most satellite missions, including Earth observation, science and communication. Similar to positioning information, timing can be used both independently and in conjunction with other data to support more complex tasks.

Accurate timing is needed to guarantee the success of space missions. It is needed on board spacecraft for many functions. One example could be time-tagged activation missions, where an instrument is activated at an exact time of day.

The **synchronisation function**, on the other hand, refers not only to the capability to provide an on-board accurate time reference for all payloads, but also to ensure that the **spacecraft will be synchronised with the time reference of assets in other locations**, either on-ground or in space.

Accurate T&S enables, for example, applications based on the principle of interferometry, were various instruments or sensors, such as radar altimeters or telescopes, are used simultaneously to gather information of their target. Measurements are then combined to obtain information of further interest.

Technologies and role of GNSS

The possibility to determine time with a high level of accuracy using GNSS receivers allows to be less dependent on **very expensive on-board atomic clocks**[10], which are based on the properties of atoms when transitioning between different energy states. The size and weight of these clocks can also be a concern for small satellites.

A GNSS receiver can, instead, be used to obtain near-atomic clock accuracy for only a fraction of the cost, providing a direct and accurate access to the Universal Time Coordinated (UTC), supporting timing and synchronisation functions. In this way, the use of GNSS receivers onboard satellites contributes to an increased autonomy.

One typical **synchronisation output** from geodetic but also spaceborne GNSS receiver is the **1 Pulse-Per-Second (PPS)** signal. The PPS signal specifies the start of a second, and is used in combination with the date and time.

Introduction to the corresponding user requirements

The following table presents the main GNSS user requirements for Timing & Synchronisation. The definition of the key GNSS performance parameters can be found in Annex A.3.

[10] Indeed, accurate and ultra-stable atomic clocks are one of the most critical components in GNSS constellations. Each Galileo satellite, for example, is equipped with four atomic clocks.

Timing & Synchronisation		
Timing Accuracy	Narrowband communications in LEO	<1 ms
	Broadband communications in LEO	<100 ns
	IoT communications in LEO	<200 ns
	GEO Station Keeping	750 ns (RMS)
	EO: SAR	<50 ns (RMS)
	EO: Optical	<100 ns (RMS)
Time Reference	Access to UTC	Yes
	Access to TAI	Yes
Service area	Geographical coverage	Global

Table 5: GNSS user requirements for Timing & Synchronisation

2.4.2 GNSS Receiver supporting or acting as Mission Payloads

This segment groups all applications where a GNSS receiver might either directly be used as a sensor for scientific and commercial missions, or supporting actively with their raw data the mission objectives of other sensors. There are several types of scientific missions where GNSS can play a role, including, amongst others, SAR (Synthetic Aperture Radar), gravity, optical, altimetry or radio occultation ones.

GNSS receivers, indeed, are sometimes installed as one of the mission payloads and not as a supporting system. Indeed, when this happens, there is typically at least another GNSS receiver on the spacecraft providing the supporting role and/or being part of the GNC subsystem.

2.4.2.1 Geocoding

The process of connecting data with its associated geographic location is known as geocoding; an example being the assignation of geographical coordinates to the pixels of an image.

Geocoding, therefore, is common in missions which main objective is to provide EO products, where for example images of different types (optical, SAR) are produced using the satellite's primary payloads and then are processed to assign a specific location on the surface of the Earth.

Data providers have traditionally performed geocoding on the ground, and based on accurate spacecraft position and attitude.

GNSS can support the mission objectives as it enables direct onboard geocoding of payload data. Depending on the accuracies achieved on-board by the GNSS receiver, in terms of (precise) orbit determination and timing, the downloaded payload data may be directly applicable by some users (thus reducing the timeliness of available information), or only require a certain degree of correction; in all cases reducing the data processing requirements.

Orbit information at the 10m level is usually sufficient. For applications such as optical sub metric imagery, where a 3D position accuracy of 0.6-0.75m (3σ) is necessary, POD is required and hence these are reported in 2.4.1.2.

2.4.2.2 Time-stamping

A timestamp is a string of characters or encoded data that indicates the time an event occurred, typically including the date and time. Data time stamping refers to recording the date and time of an event.

On-board, time-tagging is typically performed in support of the satellite's primary payload instrument measurements, the reception of data packets, etc.

In satellite imagery, for example, timestamp reflects the exact date and time of day the image was taken.

Due to its capability to provide Timing information, as already seen, GNSS becomes a natural tool to conduct onboard time-stamping of payload data. GNSS receivers specifically developed and commercialized to provide this kind of function are readily available in the market, with timing accuracies in the order of nanoseconds.

The required timing accuracies as per UCP's 2020 and 2023 are 50-100ns (RMS) and <75ns, respectively.

2.4.2.3 Atmospheric Radio-Occultation

Description of the application

Radio-Occultation can be defined as the computation of atmospheric profiles (pressure, temperature, humidity) from the bending of signals received by a properly designed sensor.

The deviation of light or any other form of electromagnetic wave, with respect to a straight line, as it travels through the atmosphere is known as **atmospheric refraction**. The level of refraction, or the refractivity along the propagating path, varies according the density of the air, which is a function of pressure, temperature and humidity properties, in a way that the *refractivity index* increases with the density. Refractivity of the atmosphere can sometimes be observed during sunrises and sunsets, when the human eye might perceive various deformations of the Sun's apparent shape.

Technologies and role of GNSS

The atmospheric refraction phenomenon can be exploited also on-board **LEO satellites to conduct the so-called 'radio-occultation' measurements (RO),** using GNSS signals instead of the Sunlight. The concept is depicted in Figure 10.

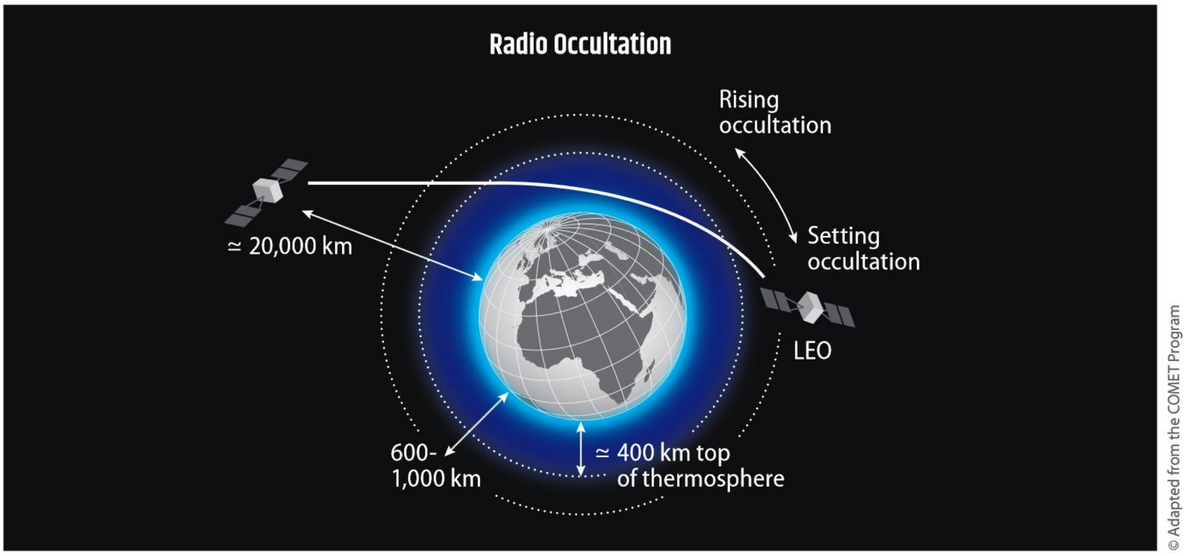

Figure 10: Radio-Occultation diagram (source: [RD19])

Radio-occultation makes use of a GNSS receiver on-board a LEO satellite which tracks the signal from an *occulting satellite*. This term refers to that GNSS satellite which is about to occult from the LEO, in the period just before satellite set (setting occultation), or rise (rising occultation). GNSS-RO requires limb-looking geometry, observing GNSS signals tangentially through the Earth's atmosphere. This geometry is fundamentally different from GNSS-R (nadir/zenith looking). As shown in the figure, the signal has to travel through the atmosphere via several layers prior to reaching the LEO, bending its path and modifying the signal in a characteristic way. Combining the measurements on-board the LEO with precise satellites' position and velocity information, the Earth's atmosphere and ionosphere are profiled (in terms of temperature, humidity (water vapour) and electron density) with high vertical resolution and global coverage.

Introduction to the corresponding user requirements

A LEO POD 3D positioning resolution of 40cm (95%) is typically adequate for RO measurements.

With a different metric though (RMS), the next institutional EU missions will be requiring < 5cm. These requirements are reported in chapter 2.4.1.2.

However, RO missions can only produce accurate atmosphere and ionosphere profiles when also accurate GNSS orbits and clocks are made available in some form (e.g. external commercial service, Galileo HAS). For this reason, the set of unique requirements brought by RO missions refer also to these accurate GNSS orbits and clock bias and the service providing them. GNSS-RO receivers must be robust against signal degradation due to atmospheric effects, reliable over long mission durations.

The following table presents the main GNSS user requirements for Radio-Occultation.

GNSS user requirements for Radio-Occultation		
Accuracy	Of GNSS orbits	<2 cms (1D, RMS)
Timing Accuracy	Of GNSS clocks	<0.05 ns (1σ)
Availability	Of the service providing accurate orbits and clocks	>99.5%
Latency	Of the service providing accurate orbits and clocks	<5 minutes

Table 6: GNSS user requirements for Radio-Occultation

GNSS-RO is based on the use of precise dual frequency receivers - which shall support at least L1/L5 & E1/E5 for improved retrieval accuracy – for ionosphere correction, phase measurements and is today a recognised, consolidated and well-established technique, ideally suited to study weather forecasting and atmospheric processes, climate monitoring and model verification, and space weather and ionospheric research.

Some notable satellite missions that incorporate GNSS-RO research are the German mission CHAMP, the US-German mission GRACE, and the US-Taiwan FORMOSAT/COSMIC mission.

Most recently, the Copernicus Sentinel-6 Michael Freilich satellite also carries a GNSS-RO instrument to generate profiles of atmospheric parameters used by weather forecasting services. The GNSS-RO instrument has a forward-looking antenna array inclined towards Earth limb to track the GNSS satellite signals as they cross Earth's atmosphere and disappear below the horizon. A second array (#2 in the figure below) is accommodated on the aft external bulkhead panel to acquire occultation profiles from the opposite direction. The occultation antennas use GPS and GLONASS. Finally, a dedicated zenith pointing antenna uses GPS satellite signals for the GNSS-RO's own POD.

The GNSS-RO landscape has also been transformed by commercial small-satellite constellations, such as Spire Global, GeoOptics (CICERO), and PlanetIQ, which provide dense, low-latency GNSS-RO data sets tailored for operational weather forecasting, climate monitoring, and space weather applications.

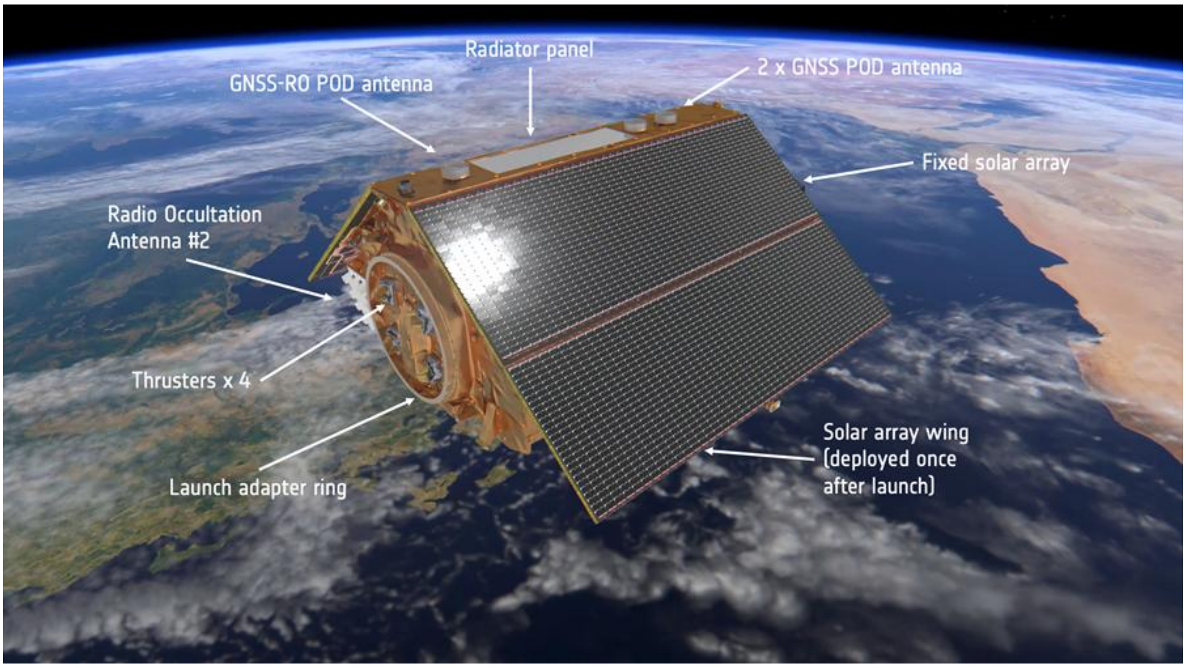

Figure 11: Sentinel-6 Michael Freilich Instruments, top view (source: ESA)

In addition, recent research on **polarimetric GNSS Radio-Occultation (RO)** is extending traditional refractivity-based atmospheric profiling by exploiting polarization-dependent signal effects. Dual-polarization RO observations enhance sensitivity to atmospheric microphysics, including cloud liquid water, ice particles, and hydrometeor distributions, improving the characterization of water-vapor gradients and mixed-phase clouds. Ongoing activities focus on developing retrieval algorithms, validating polarimetric observables, and designing advanced receivers and antennas capable of capturing orthogonal polarizations. These efforts aim to quantify the added value of polarimetric RO for weather forecasting and climate monitoring and to prepare its future operational adoption.

2.4.2.4 Gravimetry ◐

Gravimetry is a discipline of geodesy particularly focussed on **studying the Earth's gravitational field**. Apart from measuring the strength of the field, gravimetry also measures the characteristics of matter producing it and its variations in intensity.

Space gravity missions can be designed following various approaches.

In the first one, a LEO satellite orbits the Earth under the influence of its gravity field while observing 3D accelerations that, ultimately, correspond to the gravity accelerations. The orbit of the satellite is determined using GNSS, and the differences with respect to an unperturbed orbit allow determining the gravity field. The former CHAMP mission made use of this form of measurement.

An alternative is a formation flying approach, where the formation acts as a large gradiometer. In this second case, two LEO satellites are placed in the same orbit (i.e. flying in formation), but separated by several hundred kilometres. Their orbits are also determined based on GNSS. Then, provided the distance between them is measured with very high accuracy (e.g. by means of a dedicated intersatellite link), the difference in accelerations experienced by both can provide information about the gravity field. In other words, variations in the gravity field cause variations in the inter-satellite range e.g. strong gravity field will affect the leading satellite accelerating it first, and separating it from the second one. This second method was used in GRACE (Gravity Recovery and Climate Experiment) and GRACE Follow-On (GRACE-FO), and is expected to continue in the upcoming GRACE-Continuity (GRACE-C), scheduled for 2028. To complement, the European mission Next Generation Gravity Mission NGGM will also use this technique, currently on track to be launched early next decade.

The third alternative is the one chosen by mission GOCE, where in-situ measurements of the acceleration measurements were collected on-board the LEO, and whose orbit determination was also based on the use of GNSS.

2.4.2.5 Space-based reflectometry ◑

Description of the application

GNSS Reflectometry (GNSS-R) is a remote sensing technique that exploits signals from Global Navigation Satellite Systems (GNSS) after they are reflected off the Earth's surface in order to retrieve environmental and geophysical parameters.

This technique is based on bistatic radar principles: the GNSS satellite acts as the transmitter, while a receiver typically embarked on another satellite captures both the direct GNSS signal and the signal reflected from the Earth's surface. By analysing the characteristics of the reflected signal, valuable information about surface properties can be extracted.

Today, several major GNSS constellations contribute to GNSS-R applications, including Galileo, GPS, BeiDou and GLONASS, ensuring global coverage and system robustness.

The growing interest in GNSS-Reflectometry is illustrated by major international space programmes, such as NASA's CYGNSS mission, launched in 2016, and ESA's HydroGNSS mission, launched in November 2025. These projects demonstrate the maturity and potential of GNSS-R for innovative observation capabilities, opening perspectives for applications in environmental monitoring, security and defence-related domains. GNSS-Reflectometry is becoming a key enabler of advanced spaceborne sensing applications.

Technologies and role of GNSS

A key technological driver for GNSS-R is the growing demand for **fast reactivity and on-board processing capabilities**. Emergency and alert-driven applications require the ability to generate timely information. While GNSS-R data is often already generated at satellite level, the transmission of data to the ground and its subsequent analysis remain limiting factors. As a result, **enhanced on-board processing and advanced receiver features** are increasingly required to reduce latency and enable near-real-time decision-making. Constraints exist both at receiver level and in the implementation of inter-satellite links, with antenna geometry and performance directly influencing achievable accuracy. Real-time GNSS-R applications are seen as a major benefit, particularly in relation to potential complementarities with existing Copernicus Earth-observation services, although their feasibility will depend on future sector evolution and receiver capability development.

Antenna performance and production scalability were also identified as critical challenges. High-end space antennas required for GNSS-R typically involve long lead times, making it difficult to scale production and respond to increasing mission demand. This issue affects both navigation and remote sensing missions and represents a bottleneck for industrial growth and timely deployment of new systems.

From a receiver design perspective, **remote sensing applications impose significantly different requirements compared to navigation**. GNSS-R missions require much higher I/Q resolution, often far exceeding the few bits commonly used for navigation. Supporting higher bit-depth processing necessitates careful customization of GNSS signal processing chains, with distinct best practices depending on whether the receiver is used for navigation, reflectometry or radio-occultation. When a GNSS receiver operates as a remote sensing sensor, design trade-offs differ substantially from those of a classical navigation receiver. Market trends indicate an increasing move toward **highly customized GNSS receiver architectures**, with the potential for harmonisation across reflectometry and radio-occultation applications, given their shared hardware components.

Timing and synchronization emerge as core performance drivers for GNSS-R. Accurate synchronization between the incoming signal and its replica is essential for geolocating measurements and determining velocities. GNSS-Reflectometry imposes stringent requirements on the RF front end and timing architecture, with very tight timing constraints extending to ground processing for certain applications.

Finally, **signal availability and certification aspects** were raised as important considerations. The weak power of GNSS signals in space presents challenges for coverage and usability, particularly for missions beyond Low Earth Orbit. In parallel, the potential need for **receiver certification** was discussed, as some application segments may require compliance with specific mission and safety standards. While not yet systematic, certification requirements could become increasingly relevant in the longer term, depending on the evolution of operational GNSS-R use cases.

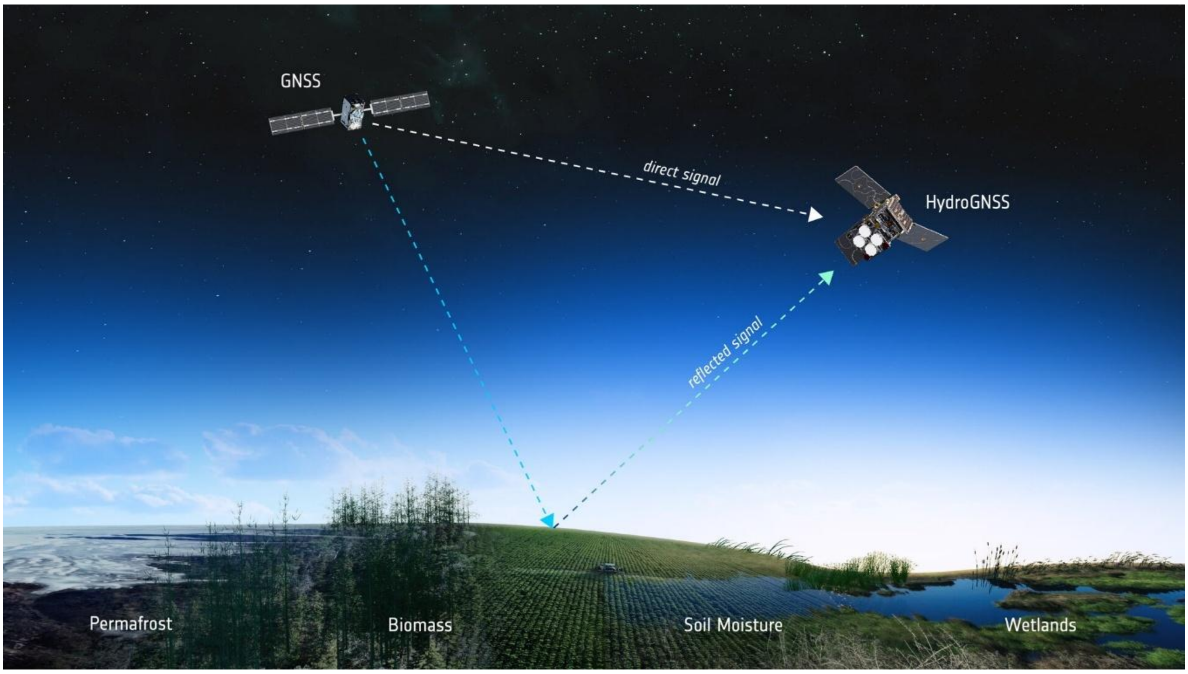

Figure 12: ESA's HydroGNSS Scout mission (image credit: ESA/ATG medialab)[11]

Other examples of future missions are GEROS-ISS (GNSS reflectometry, radio occultation and scatterometry on board the ISS), a payload to be attached to the ISS, and G-TERN (GNSS Transpolar Earth Reflectometry moNitoring system), a single-satellite mission.

Introduction to the corresponding user requirements

There are multiple initiatives requiring dedicated GNSS reflectometry receivers – based on necessary multi-frequency multi-constellation capabilities – with a growing need for rapid reactivity, particularly for alert message generation in emergency applications. Performance parameters continue to be established and improved, as techniques are enhanced and new GNSS services are declared.

The following table presents the main GNSS user requirements for GNSS Reflectometry:

[11] https://www.eoportal.org/satellite-missions/hydrognss#overview

GNSS user requirements for GNSS Reflectometry		
Accuracy	Of GNSS orbits	2-5 cm (altimetry applications)
Timing Accuracy	Of GNSS clocks	10-100 ns (1σ)
Availability	Of the service providing accurate orbits and clocks	>99.9%
Latency	Of the service providing accurate orbits and clocks	Variability by Application (e.g. 3h in operational Meteorology)

Table 7: GNSS user requirements for Reflectometry

2.4.3 GNSS Receivers onboard launchers vehicles

Launch service providers are increasingly integrating GNSS technology as key components of rocket systems into launcher design and space tugs. This integration into launch vehicles not only improves their performance, but also opens up new opportunities for commercial and scientific missions in space as cost and reliability is improved.

As navigation has been traditionally based on inertial navigation systems (INSs), the addition of GNSS supports the enhancement of the overall guidance, navigation, and control (GNC) architecture, through improving navigation accuracy, autonomy and robustness.

The following sections will provide insights into the different scenarios in which GNSS support the launchers subsegment.

2.4.3.1 Navigation in Launch and Ascend phases

Description of the application

Navigation in the launch and ascent phases supports the real-time determination of the launcher state required for execution of the nominal mission trajectory and compliance with safety constraints.

The application covers all flight segments from lift-off to orbital injection or controlled mission termination, including powered ascent, coasting phases, and stage separation events. Navigation data is used by onboard Guidance, Navigation and Control (GNC) functions to generate steering commands, manage thrust vector control, and monitor trajectory evolution with respect to predefined mission and safety envelopes. The operational environment is characterized by rapidly evolving high dynamics, transient propulsion conditions, and attitude changes driven by guidance optimisation and staging. Navigation performance must therefore remain stable and deliver predictable state errors rather than peak accuracy alone.

The traditional approach in the Ascend phase is to execute a predefined sequence of actions aimed at achieving a specific trajectory or attitude. This method, known as open-loop control, lacks the ability to make real-time adjustments in response to current conditions. Nevertheless, with recent developments and needs for better tracking and manoeuvrability, the GNSS technology has emerged to support launcher vehicle operations in coordination with other current implemented technologies.

Figure 13: Ariane 6 ascending rocket (image credit: ESA)

Technologies and role of GNSS

As mentioned, the coupling of GNSS sensors with inertial navigation systems (INSs) is now considered essential to increase the overall robustness and limit the risk of suffering from loss of signal tracking in certain phases of the flight. GNSS measurements are combined with inertial sensor data to correct drift inherent to inertial propagation and to maintain alignment with a global reference frame throughout ascent. Compared with inertial-only navigation, GNSS integration improves long-term stability, velocity observability, and time synchronization.

To cope with the high dynamics of ascent (up to 15g), GNSS receivers are designed for rapid variation, as this allows navigation continuity during short signal degradations and enhances robustness against masking and dynamic stress, making GNSS a key enabler of newer launcher navigation architectures.

Introduction to the corresponding user requirements

Space launchers do experience significant variations in the attitude of the platform; this requires the use of multiple antennas (typically, two) located around the body, with its placement being often a critical factor in order to fight against signal fading and track a sufficient number of satellites during the flight.

The minimum performance achieved should match at least the traditional IMU performances, but other factors such as robustness (either in reliability and in security) and high availability are proving essential.

The following table presents the main GNSS user requirements for Launch and Ascend phases:

GNSS user requirements for Launch and Ascend phases		
Accuracy	Of GNSS orbits	<10 m (3D, RMS)

Table 8: GNSS user requirement for Launch and Ascend phases

2.4.3.2 Stage Recovery

Description of the application

Launcher stage recovery is the process of recovering rocket stages after they have completed their primary mission of delivering the payload into space, with the final purpose of refurbish/reuse these stages on subsequent launches. Unlike traditional expendable launch systems, where each stage is discarded after use, stage recovery may involve controlled atmospheric re-entry, aerodynamic descent, and terminal landing on a ground-based platform or splashdown at sea. This innovative approach reduces costs significantly, and improves sustainability by minimising space debris and need for new materials.

Navigation functions must remain effective across multiple flight regimes to support autonomous decision-making under limited ground interaction. The recovery sequence may typically include long ballistic or guided descent phases, followed by a final phase of stringent positional and velocity requirements, as the stage need to target precise recovery zones, avoid dispersion, and ensure compliance with operational safety needs. In addition, these tasks are expected to be coordinated with recovery operations, demanding accurate localization for landing, particularly in maritime scenarios where recovery assets depend on precise position information.

Figure 14: Rendering of MaiaSpace's first stage recovery (source: MaiaSpace)

Technologies and role of GNSS

Although the recovery of the first stage is still in development for the majority of rocket launch companies, the integration of GNSS into the flight control loop is deemed essential, similarly to launch and ascend phases. In fact, enhanced precision during these critical phases is a major driver, ensuring safe descent and controlled landing, especially when targeting predefined landing sites. GNSS measurements can correct the inertial drift accumulated during previous phases, enabling a better accurate targeting of the recovery area.

In the terminal phase, GNSS is commonly complemented by altimetric sensors, such as radar or laser altimeters, to reinforce vertical observability. The combined use of GNSS and complementary sensors improves robustness, repeatability, and fault detectability, which are key requirements for autonomous and reusable launcher recovery systems.

Potential challenges such as signal attenuation and disturbances during re-entry, makes hybridisation still a need to ensure continuity during temporary outages. Subsequent reacquisition strategies allow GNSS measurements to be reintroduced once signal conditions permit, without destabilizing the navigation solution.

Introduction to the corresponding user requirements

The following table presents the main GNSS user requirement for Stage Recovery:

GNSS user requirements for Stage Recovery		
Accuracy	Of GNSS orbits	<0.2 -1 cm

Table 9: GNSS user requirement for Stage Recovery

2.4.3.3 Flight Termination Systems

A Flight Termination System (FTS) is a critical safety mechanism that ensures the safe and controlled destruction of rockets or missiles in emergencies or deviations from their intended flight path. FTSs are essential to ensure the safety of launch operations, protecting both ground personnel and astronauts. In the event of a flight anomaly, the Flight Termination System (FTS) is designed to deactivate every power stage and propulsion system, potentially terminating the mission.

Traditionally, FTS relies on a combination of airborne and ground-based subsystems such as radar stations, telemetry antennas, command antennas and human operators who can terminate a mission if the launcher deviates from its intended path. The on-board FTS component includes a receiver, a safe & arm device, and a termination system. The receiver gets signals to initiate flight or termination. The safe & arm device then arm and triggers a detonation command. This initiates the termination sequence, resulting in the disintegration of the vehicle by aerodynamic forces.

GNSS can improve the autonomy, performance and reliability of FTS systems and therefore its integration into launchers can be a significant enhancement. The RCC324 standards [RD23] set a high redundancy and accuracy (0.3 m/s for velocity and 100 m for position within a 1 sigma interval), which may be achieved by hybridisation of inertial and GNSS data, although reliability will be strongly demanded.

2.4.3.4 Spaceport's ground transport vehicles

These types of vehicles refer to the mobile assets that are used to support launch operations within spaceport boundaries, mainly rocket vehicle transporters and mobile integration platforms, which are used to support transportation between integration facilities, launch pads, and other areas. As these operations takes place in controlled, safety-critical environments, precise positioning and controlled routing requirements are mandatory.

The use of GNSS is currently under study, in order to support these operations by improving the positioning and timing information used with greater reliability, thus enhancing operational efficiency, traceability, and safety. With GNSS-based positioning, either stand along or combined with other technologies such as local positioning aids, enables a variety of applications such as geofencing, route verification, or spatial awareness within the spaceport, especially with semi-autonomous or autonomous ground vehicle concepts. Additionally, it will also support integration with digital spaceport management and safety systems.

2.4.4 GNSS Receivers for Deep Space Applications

Considering the attenuation of GNSS signals with the travelled distance and also the fact that the farthest the satellite goes from the Earth the GNSS signals are received from a narrower cone (i.e. with a bad geometry), the use of Satellite Navigation on orbits outside Cislunar space is not of significant added value from the position point of view.

For applications making use of GNSS above GEO orbits, the characterisation of the Multi-GNSS Space Service Volume and hence the use of Multi-Constellation receivers is of great support, due to the fact that the user shall receive GNSS signals coming from the opposite side of the Earth and, therefore, with limited visibility and availability.

In the long term, GNSS and Lunar PNT services will coexist in early stages and cooperate for Moon exploration. In any case, both will be part of a broader navigation ecosystem that will also include on-board sensors such as IMUs, altimeters and vision-based navigation systems.

2.4.4.1 Translunar Orbit

In the absence of an international definition, the **Translunar Orbit** or **Moon Transfer Orbit** can be simply defined as the path that a spacecraft going to the Moon actually flies.

Transfer orbits to the Moon can take different approaches and shapes. A possible way of reaching the Moon while maximising energy expenditures in uncrewed missions is to conduct a series of orbit-raising manoeuvres, starting from a highly-eccentrical Earth Orbit where the spacecraft is injected by the launcher. In other words, following a phased-approach allows spacecraft to reach the Moon with less propellant than a direct approach.

An example is provided below for NASA's LADEE mission. In this mission profile, the spacecraft engines perform calculated burns at the perigees P1 and P2 to reach the Moon at the apogee of what would be its fourth loop (depicted in red).

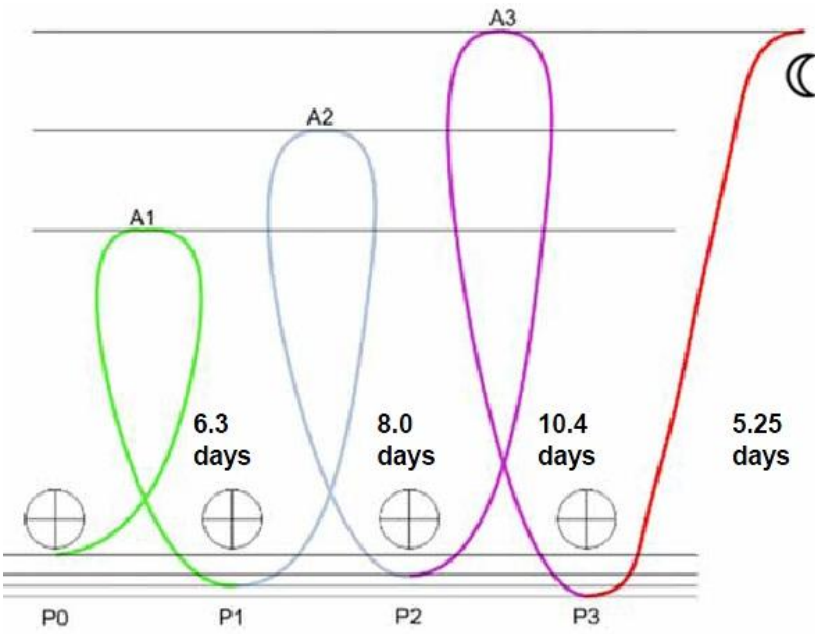

Figure 15: LADEE'S Translunar orbit & phasing (source: NASA Goddard)

The **Translunar Orbit** is one of the scenarios analysed by UNOOSA's ICG Working Group B (WG-B) in the context of their work on the "*Enhancement of GNSS Performance, New Services and Capabilities*". Simulations have shown that GNSS signals availability could be extended to lunar distances by augmenting navigation systems with a high-gain antenna and by considering and acquiring, in this way, signals coming from the GNSS satellites antenna secondary lobe. The analyses achieve performances around 50-100 m 3D RMS orbit determination and microsecond level time synchronization accuracy with high availability in real time on-board[12].

This is the first step of ESA's long-term roadmap towards establishing Moon PNT services (**the Moonlight initiative**). Although GNSS will not provide the precision and coverage needed for lunar global and high-precision activities, GNSS is expected to be used as a transitionary technology providing initial services for Translunar Orbits and Lunar Orbit operations (see next chapter).

On the performances side, GNSS shall improve timing and allow for autonomous onboard orbit and trajectory determination.

The Translunar Orbit application continues still under study and, today, thanks to the LuGRE (Lunar GNSS Receiver Experiment) mission, launched in January 2025 for a multi-week flight to the Moon, it was confirmed through a series of 11 experiments of 1 hour during the phasing loops, that GNSS signals can be acquired and solutions computed. ESA's Lunar Pathfinder, a communications relay satellite to provide long duration visibility of the Southern Lunar Hemisphere to be launched in 2026, will also contribute to the study of these orbits.

2.4.4.2 Lunar Orbit

Upon reaching the Moon's altitude, spacecraft are captured by the Moon's field of gravity and enter into Lunar Orbit. A series of manoeuvres are required to adjust the orbit as desired. The abovementioned Lunar

[12] Giordano, P. et al, "*Orbit determination and time synchronisation in lunar orbit with GNSS - Lunar Pathfinder experiment*", 72nd International Astronautical Congress, 2021

Pathfinder shall be established in an elliptical orbit to maximise its visibility from the Lunar Southern Hemisphere, for example.

Lunar Orbit navigation applications will be assisted by GNSS signals coming from Earth in a first stage. Later, thanks to the Moonlight initiative, it is expected that GNSS will be complemented by dedicated lunar orbiting satellites and lunar beacon ranging sources, so as to improve navigation performances.

The LuGRE experiment, on the other hand, **successfully achieved the first GNSS Navigation solution in lunar orbit**, with a 3D POD Position Error <200 m, using a multifrequency (GPS and Galileo) dual-frequency (L1/L5) receiver. This demonstration supports the potential use of GNSS for Positioning and Timing Synchronization of spacecrafts orbiting around the Moon. In fact, improvements in future missions will bring closer the performance to a <100 m Position User need in this application.

2.4.4.3 Moon Surface Positioning

The positioning of a spacecraft on the Moon's surface is yet in a very preliminary stage, although the LuGRE mission confirmed that GNSS can also contribute to Positioning and Timing on the Moon. Landed on the Moon's Mare Crisium basin in March 2025, the mission recorded the **first GNSS PVT Fix & Navigation Solution at the Moon surface**.

This demonstrates that GNSS Navigation Message can be demodulated reliably at the moon surface, and that the received can use Ephemeris and Clock Data from SIS. Not only INAV+ RS codes were exploited at the moon surface, but also OSNMA information was also successfully decoded whilst Galileo EWSS testing was conducted and dummy EWSS messages also successfully acquired.

Applications in need of positioning on the Moon surface include, from a high-level viewpoint, rovers, personnel/astronauts and landers. The User Needs in the Moon surface consist of a Position < 500 m and a Time Accuracy < 100 ns. It is also necessary the high Sensitivity acquisition (< 23 dBHz) and tracking (< 20 dBHz) needed for this solution. With LuGRE achieving a first GNSS PVT solution on the Moon's surface, with 3D POD with less than a kilometre, future missions will apply lessons learnt from this demonstration, proving that GNSS will support operations in the initial phases of the Moon exploring and assist lander, rover and other operations. In parallel, Lunar PNT services will be developed to offer the best suited solutions.

Under ESA's Moonlight, indeed, it is expected that a full Lunar PNT system will be gradually deployed with initial operations from 2028 onwards. A particular mission phase benefiting from this would be lunar landings, as the provision of integrity services for safety-critical applications may be part of it. Extensive research is still going-on on the establishment of a lunar navigation satellite system.

2.4.5 GNSS Receivers for Collision Avoidance

So far GNSS-only applications have been presented. This section focuses on applications exploiting synergies between SST and GNSS, in particular, **SST applications where a clear enhancement is obtained when GNSS systems are used**. These applications are mainly related to collision avoidance operations, as described next.

Collision avoidance operations are currently based on the identification of high-risk collision events involving operational satellites and the execution of collision avoidance manoeuvres reducing the associated risk below acceptable thresholds. High-risk collision events are identified based on different risk metrics, mainly, the probability of collision. Such metric depends on the relative geometry of the trajectories of the objects involved, and most importantly, on the uncertainty associated to those trajectories at the time of closest approach. Such uncertainty is due to different uncertain environmental perturbations affecting the satellite motion, such as the atmospheric drag.

On the other hand, up to a few years ago, most of the objects orbiting the Earth were not operational satellites, but space debris, making it necessary to observe and track space debris objects through SST systems. However, in the New Space era, the deployment of mega-constellations and the spread of the use of small satellites has made the share of operational satellites in the overall population of catalogued objects to increase to roughly 70-75%, increasing the frequency of high-risk collisions involving two operational satellites. Nowadays, the resolution of these events requires the interaction between the satellite operators in order to agree on the mitigation action to implement, making it necessary to implement automated systems for Space Traffic Management (STM), as a natural extension of SST systems.

2.4.5.1 Autonomous Collision Avoidance

Traditionally, collision avoidance operations have been performed mostly from the ground. These operations are normally performed by an SST system and range from the conjunction detection based on an objects catalogue (i.e. database of object properties and ephemerides) maintained with sensor observations, through the identification of high-risk events using different risk metrics such as the probability of collision, to the definition and command of a collision avoidance manoeuvre (CAM) when the risk associated to an event is too high. However, there is a trend nowadays to give more autonomy to satellites, and this also includes autonomous collision avoidance operations for cases where the satellite is equipped with GNSS receivers allowing for precise position and velocity in real time.

In this line, several satellite operators are currently operating their satellites relying on autonomous decisions taken on-board for the execution of collision avoidance manoeuvres. These on-board decisions are taken based on the information uplinked to the satellites from the ground in the form of Conjunction Data Messages (CDM), as provided by SST systems and related to the trajectories of other objects posing a risk, in combination with the position and velocity computed on-board with GNSS receivers, properly propagated to the future time of closest approach of the events.

Apart from the reduction of effort on-ground thanks to the automation of the on-board process, another benefit of this approach is that the decision about the execution of a collision avoidance manoeuvre is taken with the most updated information about the satellite position and velocity available on-board thanks to a GNSS receiver. Indeed, in case the decision was to be taken on-ground, the GNSS information computed on-board would need to be downlinked, and this is something that cannot be done in real-time with traditional downlink station networks used nowadays by satellite operators.

This real-time approach becomes especially relevant when the uncertainty of the event is dominated by the satellite with on-board capabilities, and thus, it is beneficial to take the decision on-board, where the most up-to-date information about the satellite position and velocity is available. This tends to be the case for collisions involving two operational spacecrafts.

In the case of collisions involving an operational spacecraft and a space debris object, this approach also brings benefits, even if the event is dominated by the uncertainty associated to the space debris object, whose is trajectory is known with much less accuracy. Additionally, the approach does not imply any drawback compared to an approach where decision would be taken on-ground and then uplinked to the satellite.

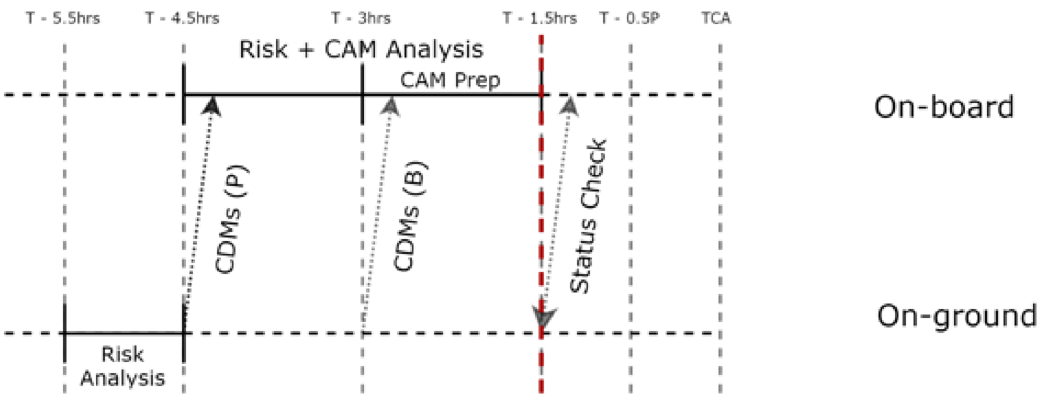

Figure 16: Timeline of autonomous collision avoidance with on-board GNSS receivers

2.4.5.2 Late Collision Avoidance Manoeuvre command

Currently, in case an upcoming high-risk collision is identified, and a collision avoidance manoeuvre is suggested by an SST system, most satellite operators wait as much as possible to take the decision about the execution of a collision avoidance manoeuvre. The reason for this is that many times the risk disappears as the uncertainty affecting the event decreases as the event gets closer in time. Indeed, the closer to the event decisions are taken, the lower uncertainty exists, and the fewer collision avoidance manoeuvres are needed. Because of this, any tele-commanding path allowing late collision avoidance manoeuvre commands improves considerably the efficiency of collision avoidance operations.

To upload manoeuvre commands to the satellites, satellite operators normally use uplink ground stations of their own, requiring from few to several hours to have visibility of the satellite from the ground stations and uplink the command, depending on the coverage of the station network. Possible alternatives with better timeliness are third party ground stations, provided as a service, or even satellite relay systems such TDRS or EDRS. In this respect, the already existing Galileo Return Link service could be exploited as a relay system to submit a late command for collision avoidance manoeuvre execution from ground to the satellite. One option is to use the Galileo Return Link to submit the full information of the collision avoidance manoeuvre via a Return Link Message (RLM) to be received by the satellite through its GNSS receiver. Alternatively, to reduce the size of the message, the information of the collision avoidance manoeuvre could be uplinked beforehand during a previous uplink opportunity using the existing ground-stations of the satellite operator, and the satellite operator would only ask the Galileo Return Link Service to submit a late go/no-go manoeuvre command. Current estimates indicate that the overall process could last 20 minutes from the moment when the decision of the execution of the manoeuvre is taken to the moment when the satellite receives the command through the Galileo Return Link, even if the process involves the Galileo Mission Control Centres, the French Mission Control Centre (FMCC) and the Return Link Service Provider (RLSP). A schematic view of the concept is presented in the following figure.

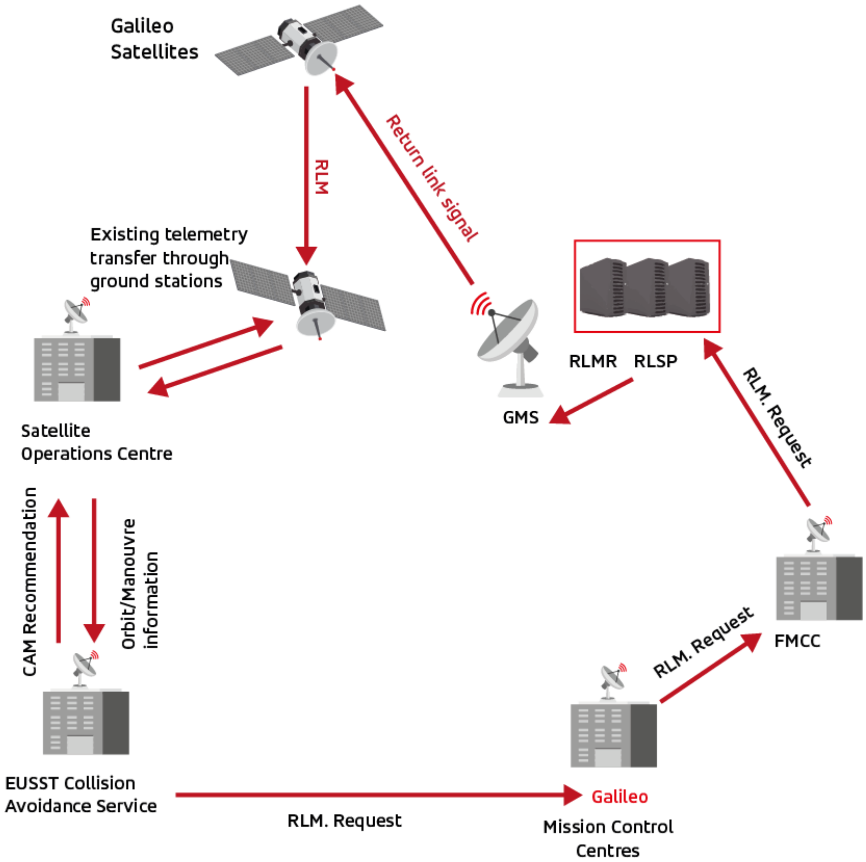

Figure 17: Use of Galileo Return Link for late commanding of collision avoidance manoeuvres

2.4.5.3 Space corridors for Space Traffic Management (STM)

As a possible way to help in Space Traffic Management, given the increase of operational satellites in orbit, an approach based on the concept of space corridors is being considered to reduce the risk of collisions and improve the safe operation of satellites. A space corridor is defined as a tube or ellipsoid moving over time where the satellite is expected to stay with high confidence. A way to ensure the satellite will remain within the space corridor assigned is enhancing the autonomy of the satellite and establishing a closed-loop between its navigation function, based on a GNSS receiver, and the propulsion function of the satellite. This approach therefore requires the satellite to be equipped with a GNSS receiver as well as possessing manoeuvring capabilities.

Additionally, it has to be noted that the size of the space corridor heavily depends on the capabilities of the propulsion subsystem of the satellite, allowing smaller space corridors the finer the thrust control is. In this respect, it is important to mention that missions equipped with chemical thrusters are able to maintain the trajectory through a tube of few hundreds of metres in radial direction for mission-related goals. With the use of electric propulsion thrusters, known to allow a finer control of the orbit via low-thrust, the size of the corridor may be much less, but would depend on the actual specific propulsion technology employed.

The main benefit of this approach is that it considerably reduces the uncertainty associated to the trajectories of the operational satellites, hence, improving the probability of collision computations for collisions involving operational spacecraft and thus the efficiency of collision avoidance operations. Indeed, the situation changes dramatically regarding uncertainty, as the trajectories are no longer the result of free flights of operational satellites through the uncertain Earth environment, but are defined and known a-priori thanks to the assignment of space corridors of given along-track length and width, where each satellite remains with high confidence.

In this concept, the role of the SST system, or its extension as an STM system, would be the assignment of the space corridors to the operational satellites, based on their propulsion capabilities and desired operational orbit, ensuring that all space corridors assigned result in no high-risk collisions. These space corridors could remain valid for a certain period of time (e.g., days or weeks) after which the space corridors would have to be re-assigned.

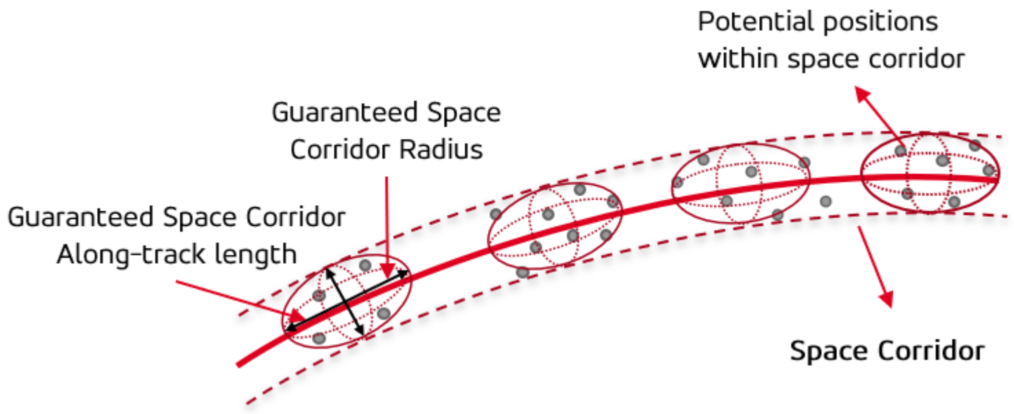

Figure 18: Space corridor concept

2.4.5.4 Trajectory broadcasting for STM using on-board GNSS receivers

A yet more advanced concept currently under evaluation to help SST and STM systems consists in equipping each satellite with a transmitter, to broadcast its current position and velocity as obtained via a GNSS receiver, and a receiver, to receive the position and velocity information broadcasted by other satellites in range. Note that depending on the relative trajectory between the spacecrafts, the time during which they remain in range for successful communications varies considerably.

In this concept, each satellite is in charge of propagating its own orbit and the orbits from other spacecrafts (based on their received position and velocity) and detect possible collisions with those spacecrafts in the near future. Hence, under this concept, the role of SST system is mainly played by the on-board software of the satellite, as it detects high-risk events based on the information received from other satellites and its own trajectory estimated with the GNSS receiver, and take collision avoidance manoeuvre decisions. However, traditional SST systems play other role, for monitoring possible conjunctions with other space debris objects as a consequence of the manoeuvres.

Some of the challenges of this approach are: sufficient range of the communications, this is, how close must be the receiving satellite to the broadcasting satellite for the communications to be successful; and availability of enough on-board computing power, to propagate the orbits of all spacecraft whose information is received, and detect possible collisions in the near future.

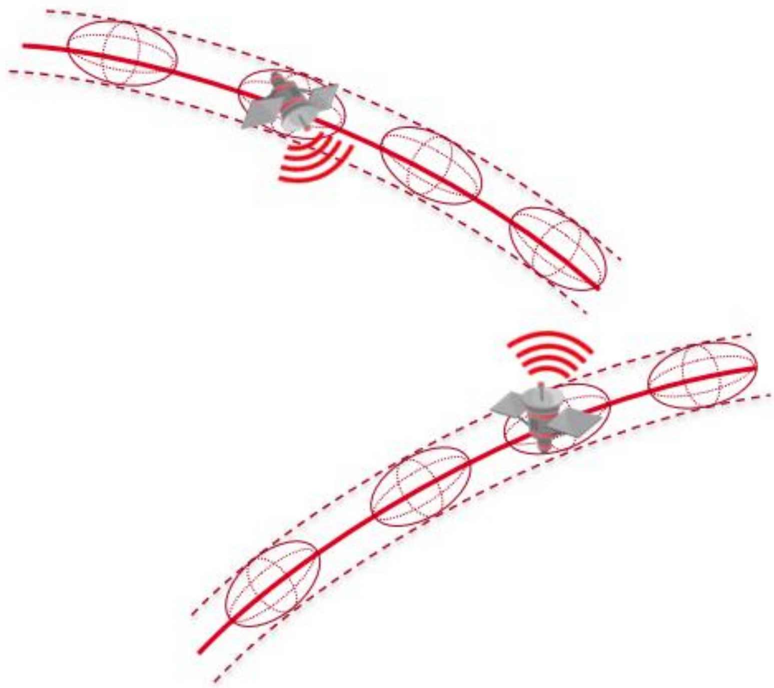

Figure 19: Concept of trajectory broadcasting for STM using on-board GNSS receivers

2.4.6 Space Operations Monitoring and Support

2.4.6.1 Launch and early operations phase

One of the most critical phases for any satellite mission corresponds to the Launch and Early Operations Phase (LEOP). It is during this phase that the satellite is released by the launcher, starts its operations and communications with the ground, performs the necessary manoeuvres to reach the target orbit and initiates the operation of each of the payloads on-board. The duration of this phase can range from a few days for traditional satellites equipped with chemical propulsion, to several months in case of GEO satellites equipped with electric propulsion and performing an Electric Orbit Raising from GTO to GEO orbit.

During this phase it is thus critical to monitor the status of the satellite by different means. In case the orbit determination process depends on the proper functioning of the satellite (e.g. on-board transponders to reply back to the ranging ground stations), it is safe to also count on passive sensors allowing to observe the object and provide measurements for orbit determination purposes.

In this context, SST systems count typically on a distributed network of sensors, normally radars for LEO and telescopes for GEO, which can be used in support of satellites during a LEOP. In these situations, the SST sensors can observe the satellite passively (i.e. without any kind of cooperation from the satellite) and provide useful observations for the accurate positioning of the satellite.

Moreover, in case of serious contingencies, these sensors generate also observations allowing to obtain information about the attitude state of the satellite, such as optical light-curves in the case of telescopes, and radar-cross-section measurements over time in the case of radars.

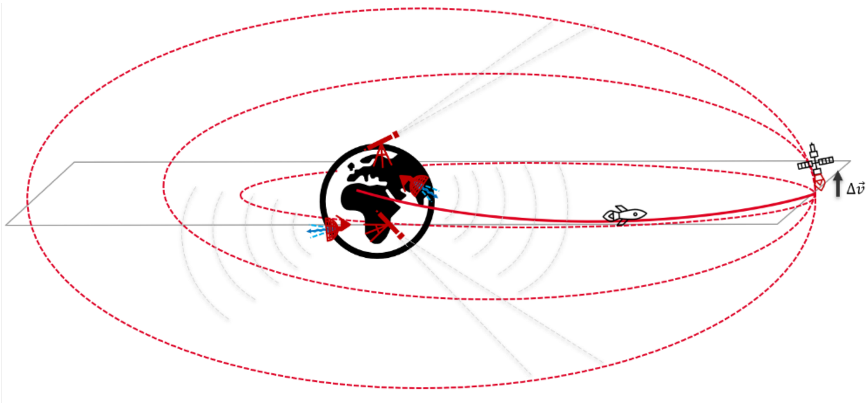

Figure 20: Sketch of Launch and early operations monitoring with SST systems

2.4.6.2 Space-Based Monitoring and Tracking

Description of the application

Space objects have been traditionally observed and tracked from ground infrastructure, such as sensors and trackers, to assess the trajectory and status of launch vehicles during flight. There is an emerging market in which these activities are performed directly from spaceborne assets that constitutes its main mission.

There are advantages by relying in spaceborne monitoring, which avoid the limitation of weather or geography that ground sensors are subject to. Additionally, advanced optics and sensors can detect more precise changes in the monitored object, thus improving in two aspects: more accurate monitoring that translate into more precise orbital data, potentially filling critical gaps, and reducing the size limitation to smaller objects, even easily detecting objects up to 10cm anywhere in LEO. On top, these products usually are transmitted faster more processed, supporting a rapid reaction when needed.

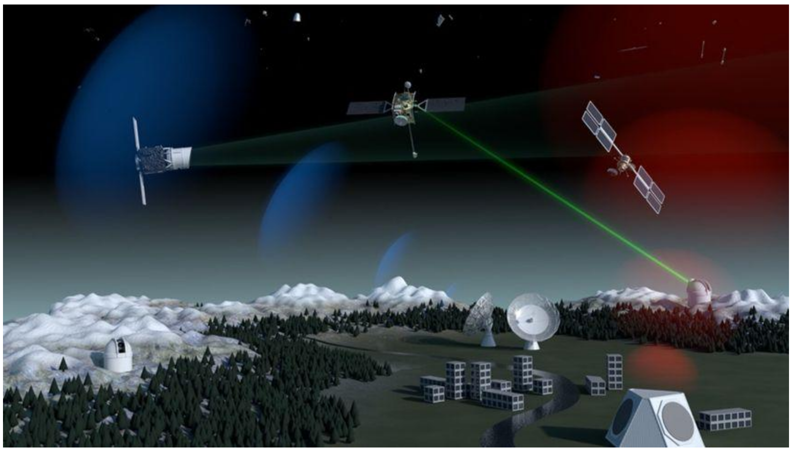

Figure 21: Monitoring and tracking from space and ground sensors (Source: ESA)

Technologies and role of GNSS

However, these space-based systems have higher need of dependable data: accuracy measurements count on on having a consistent, high-quality sensor data and reliable onboard instrumentation, as poor data compromises predictions. GNSS provides a key source of information in the activity, providing accurate positioning and a time synchronisation source for the onboard sensor instrumentation.

In addition, GNSS is also a key element for the satellite operation, orbit manoeuvres and attitude control, as mentioned, in section 2.4.1.

Introduction to the corresponding user requirements

The following table presents the requirements identified during the work performed for UCP 2025, and discussed during the event:

GNSS user requirements for Space-Based Monitoring and Tracking		
Accuracy	Of GNSS orbits	<1 m (3D, RMS)
Timing Accuracy	Of GNSS clocks	<1 ms
Availability	Of the service providing accurate orbits and clocks	>99%

Table 10: GNSS user requirements for Space-Based Monitoring and Tracking

2.4.6.3 Re-orbiting operations

Satellites perform multiple manoeuvres during their lifetime for different purposes, including station-keeping manoeuvres, to compensate the effect of the Earth environment on the orbit of the satellite, relocation manoeuvres, to position the satellite in a different operational orbit to continue with its mission, or even collision avoidance manoeuvres, to reduce the risk of an upcoming potential collision with another spacecraft or a debris object.

In case the satellite is not equipped with a GNSS receiver, the on-ground orbit determination function relies typically on measurements obtained from a network of on-ground stations. However, the number of stations is typically kept to a minimum to reduce costs, but at the same it is necessary to estimate the post-manoeuvre orbit of the satellite with a high accuracy in a short period of time after the manoeuvre. In these situations, it is possible to use a SST network, composed of telescopes, radars or both, to support the manoeuvre operations and obtain more measurements after the manoeuvre to help increasing the accuracy of the estimated satellite orbit in a short time, and also, to estimate the over- or under-performance of the manoeuvre to take possible corrections actions in the form of additional manoeuvres.

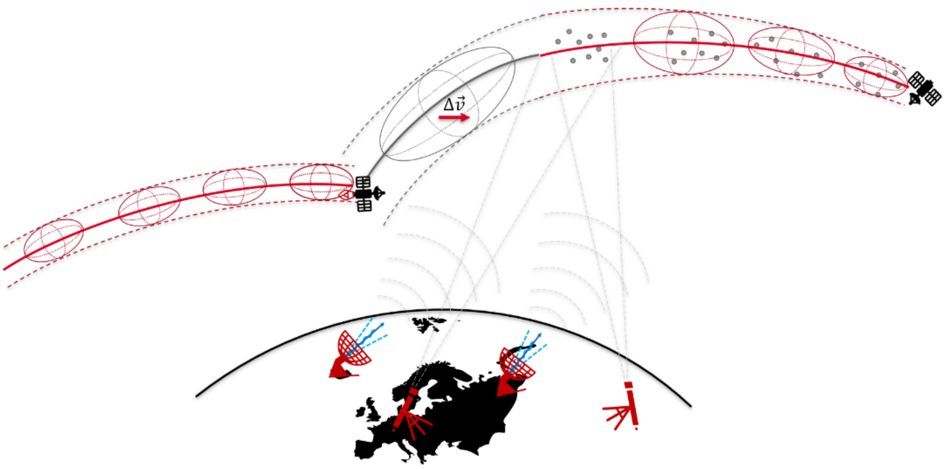

Figure 22: Sketch of re-orbiting operations monitoring with SST systems

2.4.6.4 Rendezvous and proximity operations

Rendezvous and proximity operations (RPO) correspond to the situation where a satellite, called the chaser, performs a series of manoeuvre to get in close proximity or a second satellite, called the target, or even performs a rendezvous with it. The end goal of these operations can be different in nature, ranging from equipment and personnel supply (e.g. International Space Station) to active debris removal or in-orbit servicing. In those cases, the chaser satellite is normally equipped with a relative navigation system to allow the rendezvous and proximity operations on the target satellite, which can be cooperative or uncooperative (e.g. space debris).

SST systems can support these operations observing both the target and the chaser with sensor networks, and monitor the relative orbit during the entire process to confirm through the estimation of the absolute orbits of both satellites based on the observations from the sensor network. A second possible use of SST sensors for these operations, corresponds to the estimation of the certain properties of the target satellite, such as size, shape and attitude state. This can be achieved through the analysis of sensor measurements containing information about the size and attitude of the target object. These are optical light-curves from telescopes and radar-cross-section (RCS) measurements from radars. This application is especially useful for in-orbit servicing or active debris removal missions, where the size and attitude state of the target object is not necessarily known with enough accuracy but is a mandatory information for the success of the mission.

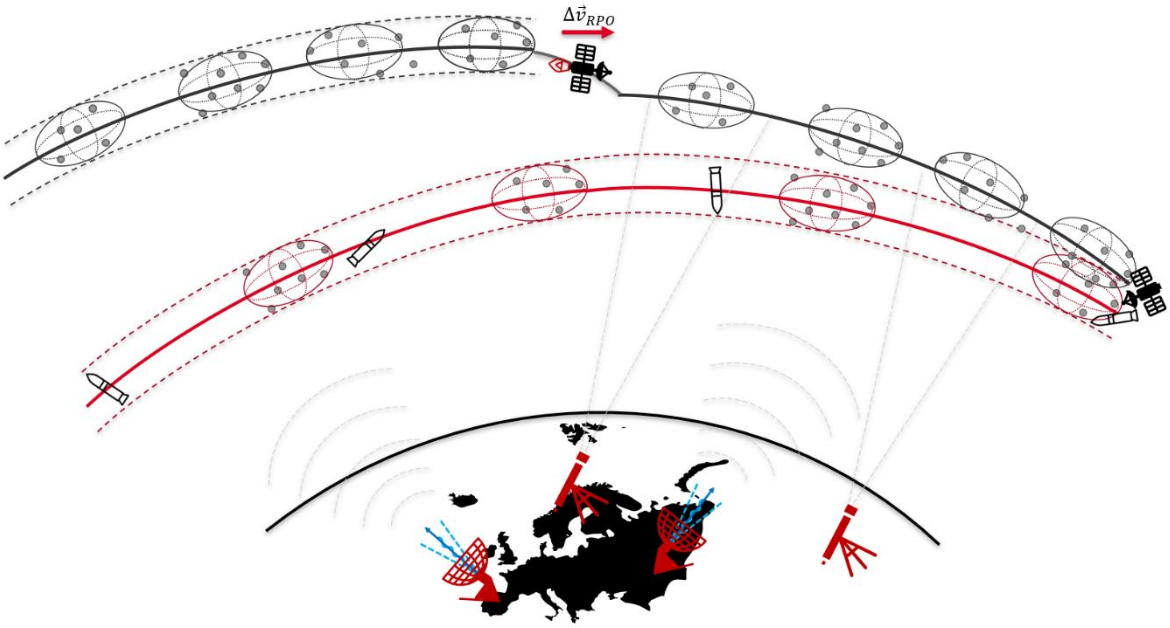

Figure 23: Sketch of Rendezvous and proximity operations monitoring with SST systems

2.4.6.5 End-of-life operations

When a satellite reaches its end-of-life, best-practices in satellite operations for space sustainability suggest either de-orbiting the satellite or decommission it to a grave-yard orbit. The former is the case for LEO satellites, whose orbit is decreased to ensure the satellite re-enters naturally the Earth due to the atmospheric drag in less than a given target (i.e., 25 years, 5 years, few days, etc.). The latter is the case for GEO satellites, whose orbit is increased at least 300 km (often more) above the GEO belt, where all operational GEO satellites are located, to ensure the satellite will not cross the GEO belt for a long time, typically more than one hundred years.

The end-of-life operations to de-orbit a LEO satellite require decreasing the altitude of its orbit through a series of manoeuvres until the atmosphere will cause naturally the re-entry of the satellite. Depending on the approach, the remaining orbital lifetime of the satellite might be several years or few days. In the former case, the satellite is passivated soon after the last de-orbiting manoeuvre, and its orbit decreases slowly until an uncontrolled re-entry takes place several years after. In the latter case, the satellite orbit is designed to target a desired re-entry location as part of a controlled re-entry. In both cases, the support of SST systems is of great importance. In the first case, SST systems can use its sensor network to observe the satellite during the process and beyond the last manoeuvre to confirm it is left in the desired target orbit and its natural decrease over time takes place as expected. In the second case, SST systems can monitor the evolution of the controlled re-entry as well as the expected re-entry date and location by its own means.

The end-of-life operations to decommission a GEO satellite to the grave-yard orbit normally imply carrying out several pairs of manoeuvres in consecutive days to raise the orbit, while keeping the eccentricity low to avoid issues in case the satellite is lost before it reaches the graveyard orbit. Because of the increase of the altitude orbit, the satellite starts drifting, unlike operational GEO satellites which remain approximately in the same position with respect to the Earth. This may cause that some of the ranging stations used normally to observe the satellite may lose visibility of the satellite. In these situations, telescopes can support the entire grave-yarding operations with its worldwide coverage, to help the satellite positioning throughout all manoeuvres. Additionally, once the satellite reaches its final grave-yard orbit and is passivated, as best-practices in satellite operations require, the use of optical telescopes also allows to confirm the satellite has been left in the right final orbit, since ranging stations can no longer be used as the satellite is no longer active.

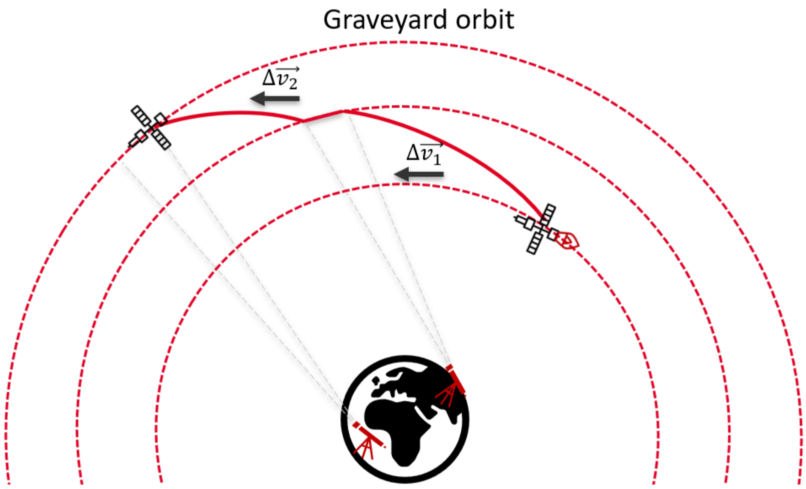

Figure 24: Sketch of End-of-life operations monitoring with SST systems

2.4.7 Limitations of GNSS and SST

As presented in section 1.2, the methodology followed to produce this report has made use, amongst others, of interviews conducted with a number of selected stakeholders operating in the field of the selected applications. It is mainly from these interviews, and reference documentation consulted as suggested by stakeholders, that the following limitations on the use of GNSS, EO and SST in *Space* have been identified.

Some limitations, on the other hand, have also been identified during the Desk Research phase, which included review of projects' documentation, scientific papers or audio-visual resources.

2.4.7.1 GNSS accuracy

Most of the needs expressed by GNSS users in the Space segment refer to the accuracies achieved onboard the spacecraft.

As has been presented in a number of applications, such requirements are today very demanding for missions where POD is an essential enabler, as could be the case of Altimetry and Radio-Occultation ones in LEO.

Centimetric accuracies can already be obtained, but not in real-time. Institutional satellite operators, for example, rely in post processing techniques based on data provided by third-party commercial services.

It is expected, therefore, that the new services and improvements implemented in GNSS (as for example Galileo's HAS) will favour the adoption of GNSS by the private sector, making new applications and businesses flourish.

2.4.7.2 GNSS power consumption

In satellite communications, nano- and pico-satellite constellations have already conducted In-Orbit Validation (IoV) for the Internet of Things (IoT) applications, such as providing connectivity to monitoring sensor stations located in remote areas.

The use of GNSS in this type of constellations is well ensured considering it provides financial and technical benefits, including a reduction in the number of instruments, a reduced dependence on ground-based stations and improved navigation performances.

However, in this context and relative to the reduced size of batteries and solar panels, the continuous use of GNSS requires a considerable amount of energy that may impact onboard power consumption limitations. Indeed, the incorporation of multi frequency and multi constellations GNSS chipsets, which increase the number of channels available for tracking, may maximise the issue.

For this type of applications, continuous positioning and centimetric accuracies are nowadays not required. Therefore, mitigations aimed at optimizing power usage include the use of relatively simple receivers and proper planning of the missions, including periods where the GNSS receivers is switched off.

2.4.7.3 Time-to-First-Fix

Linked to the mitigation described above, where the GNSS receivers can be switched off to optimize power usage onboard smaller satellites, some users require TTFFs of 5 minutes or less. The lower the TTFF is, the more efficient the power management strategies implemented by the satellite operator may be.

GNSS receivers for smaller satellites shall therefore be designed with power consumption and TTFF requirements in mind.

2.4.7.4 Signal tracking

Space-borne receivers operate in high dynamics as the relative velocities between the receiver and the GNSS satellites they are getting data from are much higher than those of their counterparts down on Earth, with an increased range of Doppler shifts (±60 kHz at low earth orbit missions versus ±5 to 10 kHz for terrestrial receivers), Doppler shift rates (100 times greater) and quickly changing satellite visibility.

Larger bandwidths are therefore required for space applications to effectively track the signals, and carrier and code tracking loops must be redesigned.

2.4.7.5 Protection against radiation

Space-borne receivers also have to face more stringent requirements with respect to radiation hardening as they have to evolve in an environment where solar and cosmic radiation are not filtered-out by the Earth's atmosphere and have to be built robust enough to stand it. GNSS electronics, especially the processor units, must be redesigned consequently.

2.4.7.6 Multipath and vibrations

The principal limitations to the use of GNSS for attitude determination, at least as back-up from more accurate technologies, are due to local effects that include multipath as well as vibrations on antennas.

On the one hand, multipath is caused by reflections and diffractions of the GNSS signal in the surrounding metallic spacecraft structures. This translates into pseudo range errors that, ultimately, affect the accuracy of measurements.

The principal mitigation techniques for this include:

- Proper antenna site selection
- Antenna designs that increase multipath rejection
- Application of absorbing materials or paintings on the reflecting structures
- Specific software implementations at receiver level (multipath compensation tables, low elevation masks, filters…).

On the other hand, vibrational effects on the antennas can change baseline lengths. The mechanic endurance of GNSS antennas and installation sites therefore must ensure survivability to the extreme vibrations inherent to a launch in a rocket.

2.4.7.7 Accessibility to GNSS antenna radiation patterns

GNSS has become a common solution for almost any spacecraft navigating above GNSS satellites, as could be the case of GEO satellites or Lunar missions.

This has been achieved, amongst others, thanks to the characterisation of the Multi-GNSS Space Service Volume (SSV) in the frame of UNOOSA's ICG. This has facilitated the development of high-sensitivity space receivers, leveraging the use of GNSS signal side lobes travelling from the other side of the Earth.

Nonetheless, work is still on-going at the ICG and, based on industry and users' requests, the committee is pursuing the publication of the antenna radiation patterns from all GNSS constellations. It is expected that this will favour the development of new spaceborne GNSS receivers.

2.4.7.8 Galileo limitations for POD

The so-called Earth Orientation Parameters (EOPs) enable the transformation between the International Celestial Reference Frame (ICRF) and the International Terrestrial Reference Frame (ITRF). In other words, they enable coordinate transformation between earth-fixed and inertial reference frames. EOPs include the precession, nutation and the **Earth Rotation Parameters**, or ERPs.

ERPs are composed by the Polar Motion (PM) and Length of Day (LOD) parameters, and high-accuracy ones are required for real-time on-board POD when the best results are to be achieved.

GPS and Beidou have been transmitting ERPs as part of their modernised civil navigation messages. In the case of GPS, for example, these are included in CNAV messages on L2C and L5, and CNAV-2 on L1C.

Galileo, on the contrary, does not provide/broadcast ERPs as part of any service (e.g. OS, HAS) nor navigation message.

For this reason, and if no auxiliary data uploads are to be provided from the ground, the use of Galileo for real-time on-board POD also requires simultaneous tracking of GPS and/or Beidou. In other words: even if a user would want to rely on a Galileo-only precise orbit determination (because indeed, Galileo provides the most accurate ephemerides amongst all GNSS), tracking of one of the other constellations would still be needed so as to obtain ERPs.

2.4.7.9 SST sensor accuracy and minimum detectable size

Within SST, two of the main limitations currently existing are related, first, to the accuracy of the observations obtained, which can range from several metres in LEO to many tens of metres in GEO, and second, to the minimum detectable size of the objects, around 10 cm in LEO and 50-70 cm in GEO with current operational sensors. These limitations impact the accuracy and type of services that can be provided based on SST systems.

2.4.8 Prospective use of GNSS and SST

2.4.8.1 The use of GNSS in space will grow

The vast majority of all the satellites in LEO today carry GNSS receivers to calculate their position. In the era of mega constellations, thousands of new satellites are estimated to be launched each year over the next decade. Consequently, the number of GNSS devices in outer space is expected to grow too.

In GEO altitudes, the use of GNSS has also consolidated, and the number of GNSS devices will grow as replacements for older generation satellites are put in orbit. In this case, however, the numbers are easily 2 orders of magnitude below with respect to LEOs.

2.4.8.2 Galileo HAS contributing to POD democratization

The Galileo High-Accuracy Service (HAS) has already been identified by spaceborne receiver manufacturers as a perfect tool to provide satellite operators with autonomous and highly accurate real-time navigation products.

The availability of accurate orbits and clocks will support advanced mission concepts and EO missions with onboard and near real-time data processing requirements.

And because HAS is provided globally and free-of-charge, the upcoming generation of receivers includes numerous models fulfilling the needs of the New Space community.

2.4.8.3 Reflectometry

GNSS-Radio Occultation has in the recent years demonstrated the positive impact it has in improving numerical weather models. As a consequence, new institutional and private missions are on the pipeline, ready to exploit GNSS signals.

In this respect, spaceborne GNSS-Reflectometry (GNSS-R) is only in its early stages and missions are only emerging, with the hope that small, low power, passive GNSS-R instruments may become deployable on small satellites. Therefore, the coming years are expected to be key to understand what the impact of GNSS-R will be as part of EO products and services, and to what extent it will then be embraced by institutional and private satellite operators.

2.4.8.4 Complementary and back-up roles of GNSS

As already described within various applications defined in sections 2.4.1 to 2.4.6, GNSS is and will be used also as complement or back-up of other technologies. This is summarized as follows:

- In attitude determination systems, GNSS can be used as back-up of more accurate systems specifically conceived to this end. With performances improving with respect to older generation receivers, as is the case of the GPS-only attitude determination system on-board the ISS, and because the same receivers could be used for orbit determination purposes (resulting in weight, maintenance and cos-related benefits), GNSS is expected to be more and more utilized in this area;
- In Lunar exploration missions, GNSS is conceived as a transitional system: it will be used to navigate during the Translunar Orbit, and may even assist navigation around the Moon (i.e. Lunar Orbit). However, for applications with more stringent requirements, in terms of accuracy, availability or even integrity, GNSS will possibly become a back-up of Lunar PNT systems. With the ESA and NASA interoperable Lunar PNT architectures being currently under definition, and with more than 250 commercial and institutional missions forecasted to be launch to the Moon between 2022 and 203, it shall be possible within the next decade to clarify what the final role/s of GNSS will be.

2.4.8.5 Extended use of SST systems

Finally, it is worth mentioning that SST systems – currently operated mainly for Collision Avoidance, Re-entry Analysis and Fragmentation Analysis – are also considered in the provision of further end-user services such as support to LEOP, re-orbiting operations, rendezvous and close-proximity and end-of-life operations, as presented above, but also others such as:

- support in case of contingency or anomalous behaviour
- identification of potentially hazardous objects
- radio-frequency interference (RFI) prediction and detection
- object characterization
- attitude estimation and characterization
- remediation and mitigation
- spawning event detection
- launch operations monitoring
- pattern of life characterization

2.4.9 Summary of drivers for GNSS user requirements

The analysis of the applications in this segment and the significant number of exchanges held with end users indicates that the main drivers for the use of GNSS are its accuracy, time-to-first-fix, cost advantage, simplicity and interoperability.

- **Accuracy**: in general, GNSS is an accurate tool for space missions, both for positioning and velocity. For many applications it is indeed the most accurate technology and therefore the main enabler.
- **Time-to-First Fix**: although the need for low TTFF figures may have not been a major concern for traditional users, where the GNSS receiver would be in continuous operation, the perception is different for some New Space entrants. The use of smaller satellites with less power resources means that energy use is a significant limitation. With receiver designs able to minimise the TTFF, the door is open for use cases where the receiver wakes up periodically before going back to sleep mode to conserve power.
- **Cost advantage**: because it does not need ground-based TT&C assistance nor infrastructure, the use of GNSS does not represent any added costs for the user. On the contrary, it is an alternative to legacy systems that in some occasions need to assume ground infrastructure costs.
- **Simplicity**: GNSS has the potential of being used for many purposes on board a spacecraft. One could imagine a scientific mission where one GNSS receiver can simultaneously be used for POD, Radio Occultation measurements, assist as part of the attitude determination function, and certainly become the main source of timing for the entire platform.
  Simplicity is also enhanced thanks to a reduced dependency from ground systems. For many applications, the spaceborne GNSS receiver works on its own, continuously and without active operations required from the ground.
- **Interoperability**: ensuring the interoperability of all GNSS systems is key to this segment, more in particular for users travelling or orbiting above the altitudes of GNSS constellations, where the availability and power levels of GNSS signals are compromised and only a multi-constellation solution guarantees the usability of GNSS. In LEO, the new receivers hitting the market are already incorporating Multi-Constellation capabilities e.g. GPS + Galileo.

2.4.10 Synergies with SST and/or SatCom

Synergies between GNSS and SST were discussed and confirmed during UCP 2023 [RD21]. Concerned applications are addressed in section 2.4.5.

Synergies between GNSS and SatCom will become relevant over the next years considering the milestones to be achieved at EU level related to the implementation of GovSatCom and IRIS[2]. As the awareness of Space users (including satellite operators and GNSS receiver manufacturers) on these SatCom components will grow, it is expected new needs will be identified during next two years. New synergies are expected to be triggered by, but not limited to, technological evolutions concerning HW miniaturisation, lower TTFF, reduced power consumption, etc).

2.5 User Requirements Specifications

The chapter provides a synthesis of the requirements described in section 2.4, on GNSS in section 2.5.1 and on EO and SATCOM in section 2.5.2. The content of this section will be updated, completed and expanded by EUSPA in the next releases of the RUR based on the results of further investigations discussed and validated in the frame of the UCP.

2.5.1 Synthesis of Requirements Relevant to GNSS

2.5.1.1 GNSS user requirements for Real-Time Navigation

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0010	The 3D position accuracy for narrowband communication satellites in LEO should be 10-100 metres (95%)	Performance (3D accuracy)	[RD14]
EUSPA-GN-UR-SPC-0020	The 3D position accuracy for broadband communication satellites in LEO should be better than 10 metres (3σ)	Performance (3D accuracy)	[RD14]
EUSPA-GN-UR-SPC-0030	The 3D position accuracy for IoT LEO mega constellations should be better than 10 metres (3σ)	Performance (3D accuracy)	[RD21]
EUSPA-GN-UR-SPC-0040	The 2D position accuracy for GEO station keeping should be better than 75 metres (3σ)	Performance (cross-track accuracy)	[RD21] [RD16]
EUSPA-GN-UR-SPC-0050	The position accuracy in radial direction for GEO station keeping should be better than 100 metres (3σ)	Performance (radial accuracy)	[RD21] [RD16]

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0060	The 3D position accuracy for GTO should be 150-600 metres (3σ)	Performance (3D accuracy)	[RD21] [RD17]
EUSPA-GN-UR-SPC-0070	The 3D position accuracy for GTO should be better than 350 metres (95%)	Performance (3D accuracy)	[RD21] [RD17]
EUSPA-GN-UR-SPC-0080	The 3D position accuracy for Altimetry satellites in LEO should be better than 10 metres (3σ)	Performance (3D accuracy)	[RD14] [RD17]
EUSPA-GN-UR-SPC-0090	The 3D position accuracy for Optical Imagery satellites in LEO should be better than 10 metres (3σ)	Performance (3D accuracy)	[RD21] [RD14]
EUSPA-GN-UR-SPC-0100	The velocity accuracy for narrowband communication satellites in LEO should be 1-10 cm/s (RMS)	Performance (velocity accuracy)	[RD14]
EUSPA-GN-UR-SPC-0110	The velocity accuracy for broadband communication satellites in LEO should be 1-10 cm/s (RMS)	Performance (velocity accuracy)	[RD14]
EUSPA-GN-UR-SPC-0120	The velocity accuracy for IoT LEO mega constellations should be better than 0.03 m/s	Performance (velocity accuracy)	[RD21]
EUSPA-GN-UR-SPC-0130	The velocity accuracy for GEO station keeping should be better than 1 cm/s (RMS)	Performance (velocity accuracy)	[RD21] [RD16]
EUSPA-GN-UR-SPC-0140	The velocity accuracy for Altimetry satellites in LEO should be 1-10 cm/s (RMS)	Performance (velocity accuracy)	[RD17]

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0150	The velocity accuracy for Optical Imagery satellites in LEO should be 1-10 cm/s metres (3σ)	Performance (velocity accuracy)	[RD21]
EUSPA-GN-UR-SPC-0160	The time to first accurate fix for IoT LEO mega constellations should be better 15 minutes	Performance (timeliness)	[RD20]
EUSPA-GN-UR-SPC-0170	The time to first accurate fix for satellites other than IoT in LEO should be better than 15 minutes	Performance (timeliness)	[RD20]
EUSPA-GN-UR-SPC-0180	The coverage needed is global	Performance (coverage)	

Table 11: Synthesis of GNSS user requirements for Real-Time Navigation

2.5.1.2 GNSS user requirements for Precise Orbit Determination (POD)

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0210	The 3D position accuracy for Altimetry satellites in LEO should be better than 0,6 metres (95%)	Performance (3D accuracy)	[RD17]
EUSPA-GN-UR-SPC-0220	The 3D position accuracy for Optical Imagery satellites s in LEO should be better than 0,6 metres (95%)	Performance (3D accuracy)	[RD17]
EUSPA-GN-UR-SPC-0230	The position accuracy in radial direction for Altimetry satellites in LEO should be better than 2 cms (RMS)	Performance (radial accuracy)	[RD21]
EUSPA-GN-UR-SPC-0240	The 3D position accuracy for Rendezvous and Docking and Formation Flying should be better than 20 cms (3σ)	Performance (3D accuracy)	[RD17]
EUSPA-GN-UR-SPC-0250	The 3D position accuracy for Rendezvous and Docking and Formation Flying should be better than 15 cms (RMS)	Performance (3D accuracy)	[RD17]

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0260	The 3D position accuracy for Radio-Occultation missions should be better than 40 cms (95%)	Performance (3D accuracy)	[RD17]
EUSPA-GN-UR-SPC-0270	The 3D position accuracy for Radio-Occultation missions should be better than 5 cms (RMS)	Performance (3D accuracy)	[RD21]
EUSPA-GN-UR-SPC-0280	The velocity accuracy for Altimetry satellites in LEO should be 1-10 mm/s (RMS)	Performance (velocity accuracy)	[RD17]
EUSPA-GN-UR-SPC-0290	The velocity accuracy for Optical Imagery satellites in LEO should be 1-10 mm/s (RMS)	Performance (velocity accuracy)	[RD21] [RD17]
EUSPA-GN-UR-SPC-0300	The velocity accuracy for Rendezvous and Docking and Formation Flying should be 1-10 mm/s (RMS)	Performance (velocity accuracy)	[RD17]
EUSPA-GN-UR-SPC-0310	The along-track velocity accuracy for Radio-Occultation missions should be better than 0.05 mm/s (RMS)	Performance (along-track velocity accuracy)	[RD21]
EUSPA-GN-UR-SPC-0320	The time to first accurate fix should be better than 15 minutes	Performance (timeliness)	[RD20]
EUSPA-GN-UR-SPC-0330	The coverage needed is global	Performance (coverage)	[RD20]

Table 12: Synthesis of GNSS user requirements for Precise Orbit Determination (POD)

2.5.1.3 GNSS user requirements for Attitude Determination

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0410	The pointing direction accuracy, with respect one axis, should be better than 0.1° (3σ)	Performance (accuracy)	[RD21]

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0420	The coverage needed is global	Performance (coverage)	[RD20]

Table 13: Synthesis of GNSS user requirements for Attitude Determination

2.5.1.4 GNSS user requirements for Timing & Synchronisation

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0510	The timing accuracy for narrowband communication satellites in LEO should be better than 1 millisecond	Performance (timing accuracy)	[RD20]
EUSPA-GN-UR-SPC-0520	The timing accuracy for broadband communication satellites in LEO should be better than 100 nanoseconds	Performance (timing accuracy)	[RD17]
EUSPA-GN-UR-SPC-0530	The timing accuracy for IoT LEO mega constellations should be better than 200 nanoseconds	Performance (timing accuracy)	[RD21]
EUSPA-GN-UR-SPC-0540	The timing accuracy for GEO station keeping should be better than 750 nanoseconds (RMS)	Performance (timing accuracy)	[RD17]
EUSPA-GN-UR-SPC-0550	The timing accuracy for Altimetry satellites in LEO should be better than 50 nanoseconds	Performance (timing accuracy)	[RD17]
EUSPA-GN-UR-SPC-0560	The timing accuracy for Optical Imagery satellites in LEO should be better than 100 nanoseconds	Performance (timing accuracy)	[RD21] [RD17]
EUSPA-GN-UR-SPC-0570	The system should provide direct access to UTC	Functional (UTC)	[RD17]**Error! Reference source not found.**

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0580	The system should provide direct access to TAI	Functional (TAI)	[RD20]
EUSPA-GN-UR-SPC-0590	The coverage needed is global	Performance (coverage)	[RD20]

Table 14: Synthesis of GNSS user requirements for Timing & Synchronisation

2.5.1.5 GNSS user requirements for Atmospheric Radio-Occultation

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0710	The accuracy of GNSS orbits used in GNSS-RO should be better than 2 centimetres (1D, RMS)	Performance (orbits accuracy)	[RD21]
EUSPA-GN-UR-SPC-0720	The availability the service providing accurate orbits and clocks should be better than 99,5%	Performance (Availability)	[RD21]
EUSPA-GN-UR-SPC-0730	The latency the service providing accurate orbits and clocks should be better than 5 minutes	Performance (Latency)	[RD21]
EUSPA-GN-UR-SPC-0740	The GNSS clocks-bias accuracy used in GNSS-RO should be better than 0.05 nanoseconds	Performance (timing accuracy)	[RD21]

Table 15: Synthesis of GNSS user requirements for Atmospheric Radio-Occultation

2.5.1.6 GNSS user requirements for Reflectometry

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0810	The accuracy of GNSS orbits used in GNSS Reflectometry should be between 2-5 centimetres (altimetry applications)	Performance (orbits accuracy)	[RD2] [RD22]

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0820	The GNSS clocks-bias accuracy used in GNSS Reflectometry should be at least between 10 and 100 nanoseconds	Performance (timing accuracy)	[RD22]
EUSPA-GN-UR-SPC-0830	The availability the service providing accurate orbits and clocks should be better than 99,9%	Performance (Availability)	[RD2] [RD22]
EUSPA-GN-UR-SPC-0840	The latency the service providing accurate orbits and clocks varies between applications. For operational meteorology should be better than 3 hours	Performance (Latency)	[RD2] [RD22]

Table 16: Synthesis of GNSS user requirements for Reflectometry

2.5.1.7 GNSS user requirements for Launch and Ascend phases

ID	Description	Type	Source
EUSPA-GN-UR-SPC-0910	The accuracy of GNSS orbits used in Launch and Ascend phases should be better than 10 metres	Performance (orbits accuracy)	[RD2] [RD22]

Table 17: Synthesis of GNSS user requirements for Launch and Ascend phases

2.5.1.8 GNSS user requirements for Stage Recovery

ID	Description	Type	Source
EUSPA-GN-UR-SPC-1010	The accuracy of GNSS orbits used in GNSS-RO should be at least between 0.2-1 metre	Performance (orbits accuracy)	[RD22]

Table 18: Synthesis of GNSS user requirements for Stage Recovery

2.5.1.9 GNSS user requirements for Space-Based Monitoring and Tracking

ID	Description	Type	Source
EUSPA-GN-UR-SPC-1110	The accuracy of GNSS orbits used in space-based monitoring and tracking should be better than 1 metre (3D, RMS)	Performance (orbits accuracy)	[RD22]
EUSPA-GN-UR-SPC-1120	The timing accuracy of GNSS clocks should be better than 1 millisecond	Performance (timing accuracy)	[RD22]
EUSPA-GN-UR-SPC-1130	The availability the service providing accurate orbits and clocks should be better than 99%	Performance (Availability)	[RD22]

Table 19: Synthesis of GNSS user requirements for Space-Based Monitoring and Tracking

2.5.2 Synthesis of Requirements Relevant to EO and SATCOM

Not applicable in the case of the Space segment.

2.5.3 Sources for the requirements

As this document is based on applications and user requirements gathered from both an extensive desk research and interviews, the analysis of the requirements has been reviewed by experts before the UCP event, then discussed at the UCP event for the approval offering the opportunity to participants to discuss about them and get the proposed updates approved or not. The reader can find the Minutes of Meeting of the event and the presentations on the EUSPA website.

3 ANNEX

A.1 Definition of key EO performance parameters

This annex provides a definition of the most used EO performance parameters and includes additional details which are relevant for the Space community.

Spatial resolution refers to the level of detail and clarity in the images, specifically the size of the smallest discernible ground features. It is determined by the pixel size, which is the smallest unit in the image that represents a spatial area on the Earth's surface. Spatial resolution is usually measured in terms of meters per pixel. Thus, a spatial resolution of 1 meter means that each pixel represents a 1 by 1 meter area on the ground.

Spectral resolution refers to the ability of a sensor to differentiate electromagnetic radiation of different wavelengths. In other words, it refers to the number and "size" of wavelength intervals that the sensor is able to measure. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. In remote sensing, features (e.g. water, vegetation) can be characterised by comparing their "response" in different spectral bands.

Radiometric resolution expresses the sensitivity of the sensor, that is to say its ability to differentiate between different magnitudes of the electromagnetic energy. The finer the radiometric resolution, the more sensitive it is to small differences in the energy emitted or reflected by an object. The radiometric resolution is generally expressed in bit, e.g. an 8-bit image has a scale of 2^8=256 nuances.

Temporal resolution relates to the time elapsed between two consecutive observations of the same area on the ground. The higher the temporal resolution, the shorter the time between the acquisitions of two consecutive observations of the same area. In absolute terms, the temporal resolution of a remote sensing system corresponds to the time elapsed between two consecutive passes of the satellite over the exact same point on the ground (generally referred to as "revisit time" or "orbit cycle"). However, several parameters like the overlap between the swaths of adjacent passes, the agility of the satellites and in case of a constellation, the number of satellites mean that some areas of the Earth can be reimaged more frequently. For a given system, the temporal resolution can therefore be better than the revisit time of the satellite(s).

Geolocation accuracy refers to the ability of an EO remote sensing platform to assign an accurate geographic position on the ground to the features captured in a scene. An accurate geolocation makes easier the combination of several images (e.g. combination of a Synthetic Aperture Radar image with a cadastral map and a vegetation map).

Spectral range refers to the wavelength range of a particular channel or band over in which remote sensing data must be collected.

Latency is the difference between the reference time of the satellite measurement and the time the final product is made available to the user (here the service provider).

A.2 Additional EO definitions

Ground deformation monitoring is the process which consists in tracking the vertical and horizontal movements of the land surface and their dynamics, whatever these movements are caused by natural phenomena (e.g. volcanic activity) or by human activities (e.g. aquifer exploitation).

Change detection is the process which aims at identifying difference in the state of “objects” (e.g. bridges, constructions, urban areas) or of a phenomenon (e.g. deforestation, soil sealing) by comparing snapshots of the situation at different times. In Earth Observation, change detection is extensively based on satellite imagery obtained through a wide variety of sensors (e.g. optical, radar, infrared, microwave, etc.

Geodesy (see [RD3]) is the earth science of accurately measuring and understanding three of Earth’s fundamental properties: its geometric shape, orientation in space, and gravitational field. The field also studies of how these properties change over time. Today, geodesy goes beyond that, being the geoscience that deals among other with the monitoring the solid Earth (which includes the monitoring of displacement, subsidence or deformation of the ground and structures due to tectonic, volcanic, and other natural phenomena as well as human activity.

Interferometric Synthetic Aperture Radar (InSAR) is a technique enabling to generate surface deformation maps based on the processing of SAR images captured at different moments in time. The processing uses the fact that if the ground has moved between the times of two SAR images of the same area, a slightly different portion of the wavelength is reflected to the satellite resulting in a measurable phase shift that is proportional to displacement. The processing therefore consists in obtaining information about the vertical movements of the ground surface by calculating the phase difference between the emitted radar signal and the signal backscattered by the surface for successive images. InSAR can potentially measure deformations of millimetre-scale during periods ranging from days to years.

Near-Real-Time (NRT) refers, when used in the context of EO applications, to applications/services/products for which the time delay between the occurrence of a given event and the availability of the outcomes of the processing of the Earth observation data corresponding to that event is considered as being not significant from a user perspective. The notion of "near real-time" is therefore depending on user requirements. For Earth observation, the corresponding time delays may range from a few hours to a few days depending on the application/service/product.

A.3 Definition of key GNSS performance parameters

This annex provides a definition of the most commonly used GNSS performance parameters, taken from [RD19]. and includes additional details which are relevant for the Space community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- System availability: the percentage of time the system allows the user to compute a position - this is what GNSS Interface Control Documents (ICDs) refer to.
- Overall availability: considers the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

Accuracy is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion – usually 95% – of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre-level: 1-10 metres.

Continuity is the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around 1*10-4 over the course of the procedure where the system is in use.

Indoor penetration is the ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

Integrity is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the "integrity concept" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

Latency is the difference between the reference time of the solution and the time this solution is made available to the end user or application (i.e. including all delays). Latency is typically accounted for in a receiver but presents a potential problem for integration (fusion) of multiple positioning solutions, or for high dynamics mobile devices.

Robustness relates to spoofing and jamming and how the system can cope with these issues. It is a more qualitative than quantitative parameter and depends on the type of attack or interference the receiver is capable of mitigating. Robustness can be improved by authentication information and services.

Authentication gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system, resulting in false data as output of the system itself.

Power consumption is the amount of power a device uses to provide a position. It will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of milliwatts (for smartphone chipsets).

Probability of false alarm refers to the likelihood of the receiver to indicate the presence of a signal when no signal is present.

Probability of detection refers to the likelihood of a receiver to detect the presence of a GNSS signal when a signal is indeed present.

Time To First Fix (TTFF) is a measure of time between activation of a receiver and the availability of a solution, including any power on self-test, acquisition of satellite signals and navigation data and computation of the solution. It mainly depends on data that the receiver has access to before activation: cold start (the receiver has no knowledge of the current situation and must thus systematically search for and identify signals before processing them – a process that can take up to several minutes.); warm start (the receiver has estimates of the current situation – typically taking tens of seconds) or hot start (the receiver understands the current situation – typically taking a few seconds).

Time To First accurate Fix (TTFaF) is a measure of a receiver's/solution's performance covering the time between activation and output of a position within the required accuracy bounds.

A.4 Definition of key SATCOM performance parameters

Link type refers to the type of communication link used for transmitting voice or data.

Availability is qualitative indication of the reliability and uptime of the communications system. It refers to the percentage of time the communication system is operational and meets the required quality of service when the application is in use.

Latency refers to the delay between the transmission of a signal and the reception of the response. This is the time it takes for a signal to travel from the sender to the receiver and back.

Bandwidth (bit rate) is a qualitative indication of the anticipated rate of data transfer when using the application. It is the amount of data that can be transmitted over the communication link in a given amount of time, usually measured in bits per second (bps).

Coverage is an indication of the geographical area that can be reached by the service. It defines the regions where the satellite signal is available and can provide communication services.

Symmetry Up/Down is the ratio between the uplink traffic (data sent from the ground to the satellite) and the downlink traffic (data sent from the satellite to the ground). This ratio indicates whether the communication link is symmetric (equal uplink and downlink capacity) or asymmetric (different uplink and downlink capacities).

Distribution refers to the method and extent to which the communication service is distributed across different regions or users. It can include the distribution of signal strength, service availability, and user access.

Setup refers to a qualitative indication of the time required to establish a voice or data communication session with the application. It refers to the acceptable duration for setting up a communication link that is sufficient to perform the intended operation, such as railway operations.

Speed: the speed at which a user is traveling, with a maximum value specified. In satellite communication, this can affect the ability to maintain a stable communication link, especially for mobile users.

Security protection refers to the measures and protocols implemented to ensure the security of the communication link. This includes protecting the data from unauthorized access, interception, and ensuring the integrity and confidentiality of the transmitted information

A.5 Other performance parameters

EO

Agility corresponds to the ability of a satellite to modify its attitude and to point rapidly in any direction to observe areas of interest outside its ground trace. High agility can improve the temporal resolution compared with the revisit time of the satellite.

Swath corresponds to width of the portion of the ground that the satellite "sees" at each pass. The larger the swath, the bigger the observed area at each pass.

Off-nadir angle corresponds to the angle at which images are acquired compared with the "nadir", i.e. looking straight down at the target. In practice, objects located directly below the sensor only have their tops visible, thus making it impossible to represent the three-dimensional surface of the Earth. High resolution images are therefore generally not collected at nadir but at an angle. A large off-nadir angle enables a wider ground coverage at each pass and the identification of features not visible at nadir, but it reduces the spatial resolution. For optical imagery, typical off-nadir angles are in the range of 25-30 degrees.

Sun-elevation angle corresponds to the angle of the sun above the horizon at the time an image is collected. High elevation angles can lead to bright spots on the imagery while low elevation angles lead to darker images and longer shadows. The most appropriate angle depends on the type of application: a high sun elevation is appropriate for spectral analysis since the objects to be observed are well illuminated while a lower elevation angle is better suited to interpretation of surface morphology (e.g. the projected shadows can enable a better image interpretation).

GNSS

Size, weight, autonomy, and power consumption. Power consumption and size are not strictly GNSS performance parameters, however they are also considered in this analysis, especially for GIS and Mapping-related applications.

- **Autonomy**. Power consumption is the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of mW (for smartphone chipsets). GNSS is considered one of the heaviest drains on smartphones batteries
- **Size, weight**. Most GIS devices used by NGOs are handheld or rugged tablets/phones, which implies that they must remain small and lightweight.

Resiliency is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions; including the ability to recover from deliberate attacks, accidents, or naturally occurring threats or incidents. A resilient system will change its way of operations while continuing to function under stress, while a robust (but non-resilient) system will reach a failure state at the end, without being able to recover.

Connectivity refers to the need for a communication and/or connectivity link of an application to be able to receive and communicate data to third parties. Connectivity relies on the integration with both satellite and terrestrial networks, such as 5G, LEO satellites, or LPWANs.

Interoperability refers to the characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, in either implementation or access, without any restrictions (e.g. ability of GNSS devices to be combined with other technologies and the possibility to merge the GNSS output with the output coming from different sources).

Traceability is the ability to relate a measurement to national or international standards using an unbroken chain of measurements, each of which has a stated uncertainty. For Finance applications, knowledge of the traceability of the time signal to UTC is essential to ensure regulatory compliance of the timestamp.

A.6 List of Acronyms

Acronym	Definition
CA	Collision Avoidance
CAM	Collision Avoidance Manoeuvre
CDM	Conjunction Data Message
COTS	Commercial-Off-The-Shelf
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System
EO	Earth Observation
EOP	Earth Orientation Parameters
ERP	Earth Rotation Parameters
ESA	European Space Agency
EU	European Union
EUSPA	European Agency for the Space Programme
EUSST	European Union Space Surveillance and Tracking
EWSS	Emergency Warning Satellite Service
FCC	Federal Communications Commission
FTS	Flight Termination System
G2G	Galileo 2^{nd} Generation
GEO	Geostationary-Earth Orbit
GNC	Guidance, Navigation and Control
GNSS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GNSS-R	GNSS-Reflectometry
GNSS-RO	GNSS-Radio Occultation
GOVSATCOM	Governmental Satellite Communications
GPS	Global Positioning System
GSA	European GNSS Agency
GTO	Geostationary Transfer Orbit
HAS	High Accuracy Service
HW	Hardware
Hz	Hertz
ICG	International Committee on GNSS
ICRF	International Celestial Reference Frame
IDS	International DORIS Service
INS	Inertial Navigation Systems
IOS	In-Orbit Servicing
IoT	Internet of Things
IoV	In-orbit Validation
$IRIS^2$	Infrastructure for Resilience, Interconnectivity and Security by Satellite
ISS	International Space Station

ITRF	International Terrestrial Reference Frame
ITU	International Telecommunications Union
LEO	Low-Earth Orbit
LEOP	Launch and Early Operations Phase
LOD	Length of Day
LRA	Laser Retroreflector Array
MCC	Master Control Centre
MoM	Minutes of Meeting
MR	Market Report
NASA	National Aeronautics and Space Administration
OSNMA	Open Service Navigation Message Authentication
PM	Polar Motion
PNT	Positioning, Navigation and Timing
POD	Precise Orbit Determination
PPP	Precise Point Positioning
PPS	Pulse Per Second
PVT	Position, Velocity and Timing
R&D	Research and development
R&I	Research and Innovation
RCS	Radar-Cross-Section
RD	Reference Document
RLM	Return Link Message
RLSP	Return Link Service Provider
RMS	Root Mean Square
RPO	Rendezvous and proximity operations
RUR	Report on User needs and Requirements
SAR	Synthetic Aperture Radar
SATCOM	Satellite communications
SIS	Signal-In-Space
SLR	Satellite Laser Ranging
SME	Small and Medium-sized Enterprise
SoL	Safety of Life Service
SPP	Single Point Positioning
SSA	Space Situational Awareness
SST	Space Surveillance and Tracking
SSV	Space Service Volume
STM	Space Traffic Management
TAI	International Atomic Time
TraCSS	Traffic Coordination System for Space
TT&C	Telemetry, Tracking and Command
TTFaF	Time-To-First Accurate Fix
TTFF	Time-To-First Fix
UCP	User Consultation Platform
UN	United Nations

UNOOSA	United Nations Office for Outer Space Affairs
US	United States
UTC	Universal Time Coordinated
WG	Working Group

Table 20: Acronyms

A.7 Reference Documents

Id.	Reference	Title	Date
[RD1]	EUSPA Market Report	EUSPA EO and GNSS Market Report (Issue 2)	2024
[RD2]	UCP 2025 MoM	UCP 2025 Minutes of Meeting of the Space Market	2025
[RD3]	UNOOSA SSV Booklet	The Interoperable Global Navigation Satellite Systems Space Service Volume (Second Edition)	2021
[RD4]	Joint Communication on STM	JOINT COMMUNICATION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL An EU Approach for Space Traffic Management – An EU contribution addressing a global challenge	2022
[RD5]	Opinion of the European Economic and Social Committee on secure SATCOM and STM	Opinion of the European Economic and Social Committee on the Opinion of the European Economic and Social Committee on the Proposal for a Regulation of the European Parliament and of the Council establishing the Union Secure Connectivity Programme for the period 2023–2027and Joint Communication to the European Parliament and the Council: An EU Approach for Space Traffic Management — An EU contribution addressing a global challenge	2022
[RD6]	European Parliament resolution on STM	European Parliament resolution of 6 October 2022 on an EU approach for space traffic management - an EU contribution addressing a global challenge (2022/2641(RSP))	2022
[RD7]	Euroconsult SST	Commercial Space Surveillance & Tracking - Euroconsult for the UK Space Agency	2020
[RD8]	1967 Outer Space Treaty	Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies	1966
[RD9]	Galileo 2nd Generation Implementing Decision	Commission Implementing Decision setting out the operational and technical specifications necessary to implement the evolution of the system established under the Galileo programme	2020
[RD10]	The Space Regulation	Regulation (EU) 2021/696 of the European Parliament and of the Council of 28 April 2021 establishing the Union Space Programme and the European Union Agency for the Space Programme and repealing Regulations (EU) No 912/2010, (EU) No 1285/2013 and (EU) No 377/2014 and Decision No 541/2014/EU	2021
[RD11]	Space Strategy for Europe	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Space Strategy for Europe	2016
[RD12]	EU Approach for Space Traffic Management	Joint communication to the European Parliament and the Council. An EU Approach for Space Traffic Management, An EU contribution addressing a global challenge	2022

Id.	Reference	Title	Date
[RD13]	EUSPA SATCOM Market and Technology Report	EUSPA Secure SATCOM Market and User Technology Report	2023
[RD14]	Springer Handbook of GNSS	Springer Handbook of Global Navigation Satellite Systems, Teunissen Montenbruck (ISBN: 978-3-319-42926-7)	2017
[RD15]	ITU recommendation on GEO Station Keeping	Recommendation ITU-R S.484-3 Station-keeping in longitude of geostationary satellites in the fixed-satellite service	2001
[RD16]	GOES-R requirements	Strategies to Maximize Science Data Availability for the GOES-R Series of Satellites	2018
[RD17]	STP-GNS-SUR-006 Issue 6.0	GENESIS Project: R&D for a Galileo Space Service - Space User Requirements (SUR)	2019
[RD18]	TriHex Mission Concept	TriHex: combining formation flying, general circular orbits and alias-free imaging, for high resolution L-band aperture synthesis	2023
[RD19]	GNSS Technology Report	GSA GNSS Technology Report (Issue 3)	Sept. 2020
[RD20]	User Requirements Interviews	Validation Interviews	2023
[RD21]	UCP 2023 MoM	UCP 2023 Minutes of Meeting of the Space Market	2023
[RD22]	User Requirements Interviews	Validation Interviews	2025
[RD23]	RCC 324-11	Global Positioning and Inertial Measurements Range Safety Tracking Systems' Commonality Standard	2011

Table 21: Reference documents

EUSPA Mission Statement

The mission of the Agency is defined by the EU Space Programme Regulation.

EUSPA's mission is to be the user-oriented operational Agency of the EU Space Programme, contributing to sustainable growth, security and safety of the EU. In the execution of its mission, EUSPA counts on strong partnerships with the European Commission, European Parliament, Member States, European Space Agency, and private actors across the EU.

EUSPA:

- Provides state-of-the-art, safe and secure positioning, navigation and timing services based on Galileo and EGNOS, cost-effective satellite communications services for EU GOVSATCOM and soon IRIS² and Front Desk services of the EU Space Surveillance Tracking whilst ensuring the systems' service continuity and robustness.

- Promotes and maximises the use of data and services offered by Galileo, EGNOS, Copernicus, EU GOVSATCOM and soon IRIS² across a broad range of domains.

- Fosters the development of a vibrant European space ecosystem by providing market intelligence, and technical know-how to innovators, academia, start-ups, and SMEs. The Agency leverages Horizon Europe, other EU funding, and innovative procurement mechanisms.

- Implements and monitors the security of the EU Space Programme components in space and on the ground with the aim to enhance the security of the Union and its Member States. To do so, EUSPA operates the Galileo Security Monitoring Centre (GSMC).

- The EU Space Programme Security Accreditation Board is established within the Agency, representing the security accreditation authority for all of the EU Space Programme's components.

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