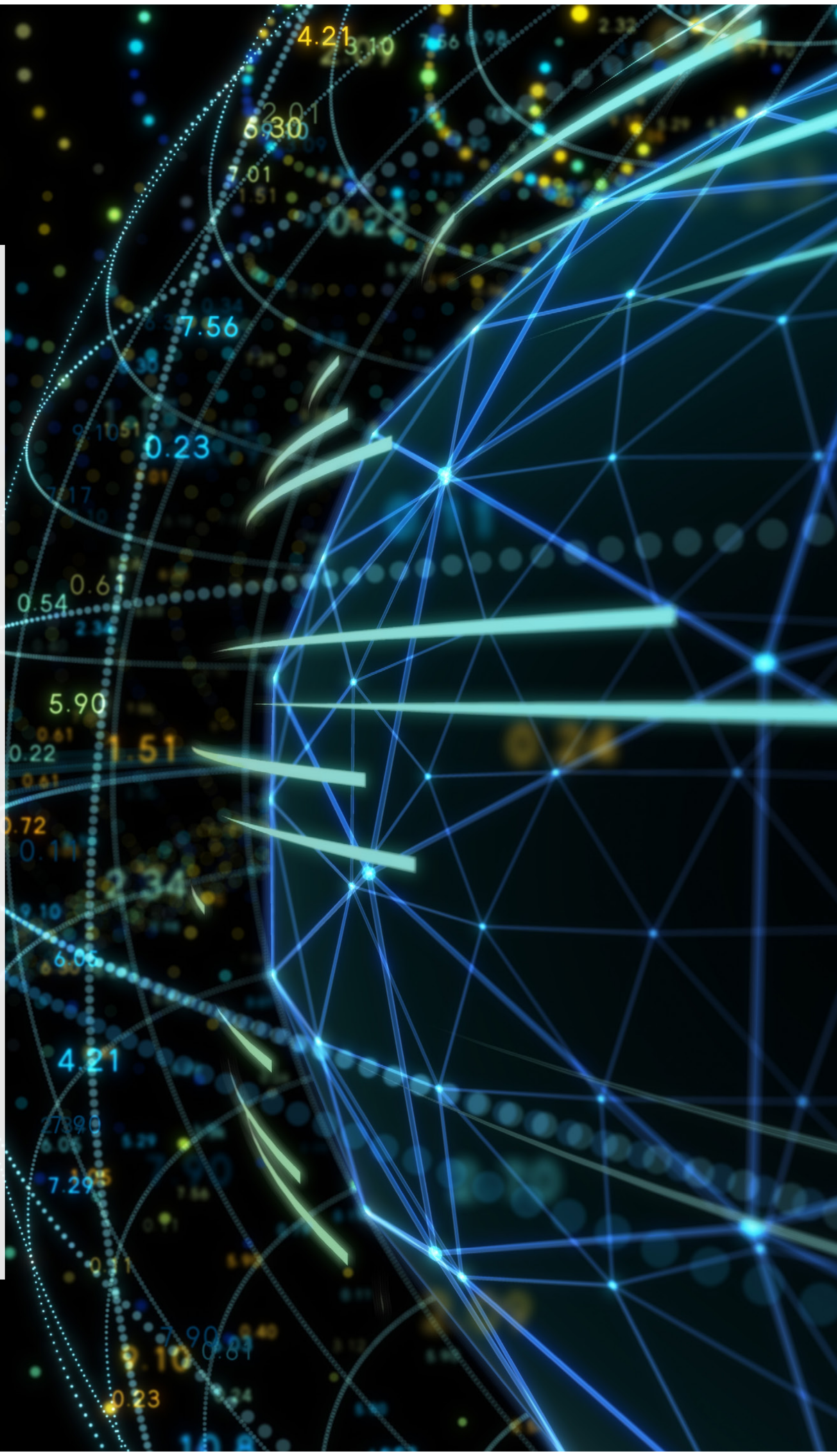

# REPORT ON SPACE USER NEEDS AND REQUIREMENTS

Outcome of the EUSPA
User Consultation Platform

June **2021**

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# 01 INTRODUCTION AND CONTEXT OF THE REPORT

GNSS-based technologies are increasingly penetrating most of the economic sectors and asking for ever-more demanding user needs and requirements. Satellite navigation has therefore a great role to play in the ongoing transformation of our society – in which space activities are also developing at an unprecedented pace.

Originally designed to offer positioning and navigation services to terrestrial users, GNSS has indeed now also proven its worth as a valuable tool for in-space applications. Real-time spacecraft navigation based on spaceborne GNSS receivers is becoming a common technique for low-Earth orbits (LEO) and geostationary orbits (GEO), allowing satellites to self-determine their position using GNSS, reducing dependence on ground-based stations. Deriving Earth observation measurements from GNSS signals is also becoming usual, adding-up to the list of established and potential uses of GNSS in outer space.

The space environment yet presents differences from the terrestrial environment preventing to assume that a receiver working flawlessly on the ground will properly work in space. With an ever-increasing number of spacecrafts, the multiplication of GNSS assets worldwide and the continuous development of GNSS spaceborne solutions, the definition of appropriate functional and performances user requirements has therefore become essential. The objective being to drive technological developments and to ensure that EGNSS services correspond to the demanding user reality.

In line with these emerging needs and uses of GNSS in Space, it is relevant to point out that Galileo will be formally providing a Service for Space users – a Galileo Space Service Volume (SSV), as announced at the UPC [www.euspa.europa.eu/euspace-applications/euspace-users/user-consultation-platform-2020#Space].

In addition to that, the international community is working on the definition of an Interoperable GNSS Space Service Volume. This definition has been based so far on the outcomes of a work carried-out within the Working Group B of the United Nation International Committee on GNSS (UN ICG). The first version of the booklet collecting the outcomes of this WG has been published in its first version in 2018 [RD10][1] , and the group is now preparing an update to be published in short term.

The User Consultation Platform (UCP) is a periodic forum organised by the European Commission and EUSPA involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers, application developers and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. The event is a part of the process developed at EUSPA to collect user needs and requirements and take them as inputs for provision of user driven Galileo and EGNOS services. In this context, the objective of this document is to provide a reference for the European GNSS Programmes and for the Space community, reporting periodically the most up-to-date GNSS user needs and requirements in the sector.

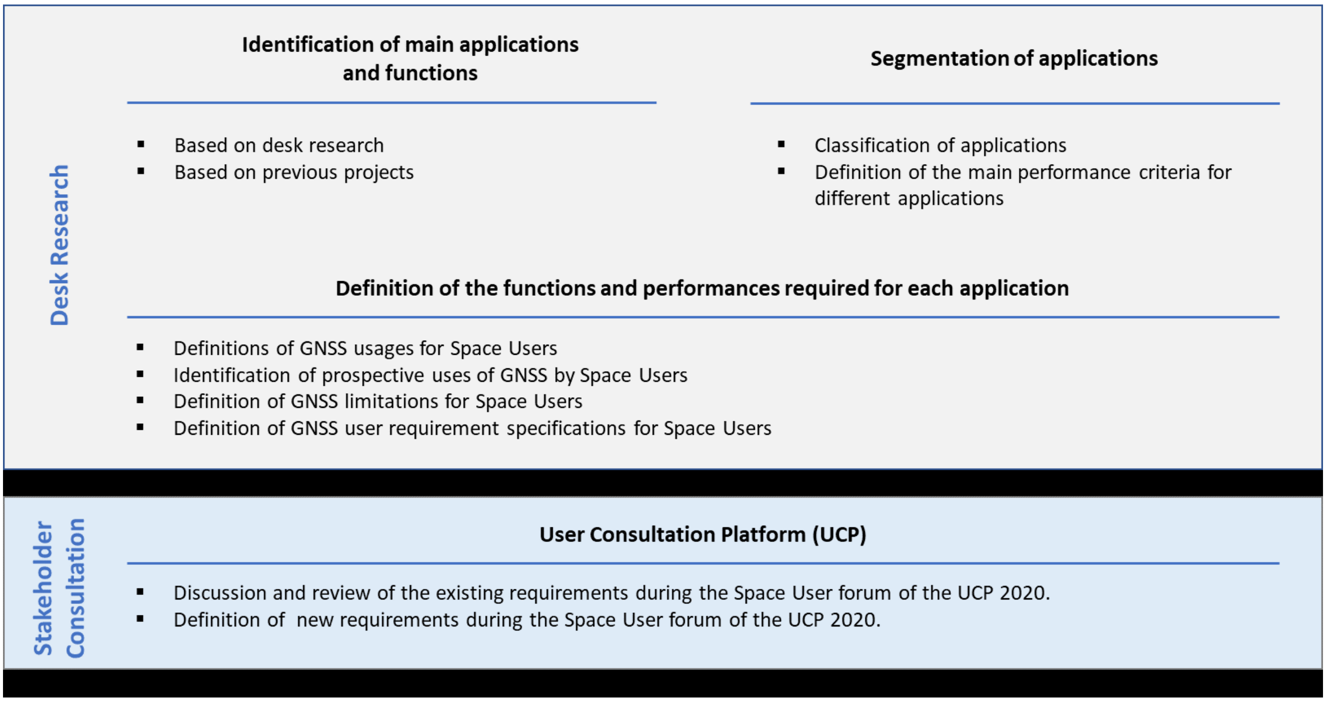
> The GNSS-based technologies are increasingly penetrating most of the economic sectors and asking for ever-more demanding user needs and requirements.

This report is considered a "living document" in the sense that it will serve as a key input to the next UCP event where it will be reviewed and subsequently updated. The UCP will be held periodically (e.g. once per year) and this report will also be periodically updated, to reflect the evolution in the user needs, market and technology captured during the UCP. It will provide EUSPA with a clear view of the current and potential future user needs and requirements, serving as an input to the continuous improvement of EGNSS services.

Finally, the report being publicly available, it also aims to serve as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of location technologies. It must be noted that the listed user's needs and requirements cannot usually be addressed by a single technological solution but rather by combination of several signals and sensors. Therefore, the report does not represent any commitment of the European GNSS Programmes to address or satisfy the listed user needs and requirements in the current or future versions of the EGNSS services.

1 See https://digitallibrary.un.org/record/3829212

**Figure 1:** Space Users Requirements Methodology




## 1.1 METHODOLOGY

As presented here-above, the analysis performed under this project was split in two main parts:

- First, a desk research-based analysis was performed to identify the main GNSS applications for Space Users, the key drivers for their performance requirements together with the main requirements, etc.
- This allowed to define a series of user requirements that were discussed at the occasion of the Space User forum of the User Consultation Platform that took place in December 2020, in order to validate and fine-tune the analysis performed through desk research.

The steps described above have resulted in the outcomes that are presented in detail hereafter.

## 1.2 SCOPE

This document is part of the User Requirements documents issued by EUSPA for the Market Segments where Position Navigation and Time (PNT) play a key role. Its scope is to cover user requirements on PNT solutions from the strict user perspective and the market conditions, regulations, and standards that drive them.

Therefore, the document is structured as follows: an overview of the main market trends for space users (Section 4), followed by a detailed analysis of GNSS space users' requirements (Section 5). Finally, section 6 provides a detailed overview of the GNSS User Requirements Specifications in Space per type of application.

# 02 EXECUTIVE SUMMARY

This report aims at enhancing the understanding of market evolution, strong points, limitations, key technological trends and main drivers related to the uptake of GNSS solutions by space users. These are essential elements in order to frame the associated technology and service offering development based on the requirements of the relevant user communities.

**Key trends and market evolution**

The GNSS market for space users has been evolving extremely fast over the last decade, resulting from deep paradigm shifts in the space industry. Characterised by the opening-up of the sector to non-governmental and more business-oriented actors, a disruptive commercially driven approach to space has emerged, coupled to important technological advances, resulting in an increasing number of satellites. While entering the third millennium, about 800 satellites were actively orbiting the Earth. Twenty years later, this number has now exceeded 3,000 satellites and is expected to quadruple over the next decade. Highlighting the democratisation of space in our society and the convergence of the sector with the ever more digitalised human activities, the development of new satellite megaconstellations systems on Low Earth Orbits (LEO) is a marker of this new era.

While spaceborne GNSS-based solutions have now proven their worth for a number of applications, the booming number of new satellites has an undeniable impact on the market. The diversification of spacecraft manufacturers is therefore coupled to a multiplication of spaceborne GNSS-based solutions developers for small satellites, as well as additional spacecraft integrators and operators. With satellites manufactured in batch, launches occurring every month, equipment being mass produced and processes being industrialized, the space environment is progressively considered as a commodity, and spaceborne GNSS receivers as an increasingly common and relevant solution for space users.

**Current and Prospective use of GNSS for Space Users**

Space users being here considered as the user of spacecrafts operating in the region of space where satellites are flying and can be reached by GNSS signals, ranging from the lowest Low Earth Orbits (LEO) altitudes (i.e. 300 km) up to Moon Transfer Orbit (MTO). Spaceborne receivers are not fundamentally different from GNSS receivers used in other market segments down on Earth. They perform the same operations and provide the same PVT services as a classical receiver, but they have to respect some specific constraints due to the environment they are expected to evolve in (e.g. high dynamics, reduced signal power and visibility, radiation hardening, etc.). Depending on the mission expected from the spacecraft, the role of the embedded GNSS receiver(s) varies. 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 purpose on a translunar trajectory is also considered as relevant.

As previously anticipated in the Introduction of this document, these new needs and uses of GNSS have been recognized by GNSS service providers (including European ones) who have analysed and characterised the availability and performance of their systems, not only in the most commonly used LEO orbits, but also from MEO up to GEO. This characterisation considers also the different possible uses of GNSS in terms of number of constellations (i.e. mono or multi) and frequencies used (i.e. single, double or triple).

In this respect it is relevant to point out that Galileo will be formally providing a Service for Space users – a Galileo Space Service Volume (SSV) - as announced at the UPC [www.euspa.europa.eu/euspace-applications/euspace-users/user-consultation-platform-2020#Space]. With the rapid development of space activities and the new challenges it raises (e.g. sustainability issues, security aspects, space resources mining, etc.), new innovative mission concepts are also considered and progressively made possible. Among them, two are further explored, namely the in-orbit servicing (referring to the refuelling or the repairing of space satellites while in orbit) and the navigation all around the Moon, including its dark side.

**Drivers for users' requirements and EGNSS proposition**

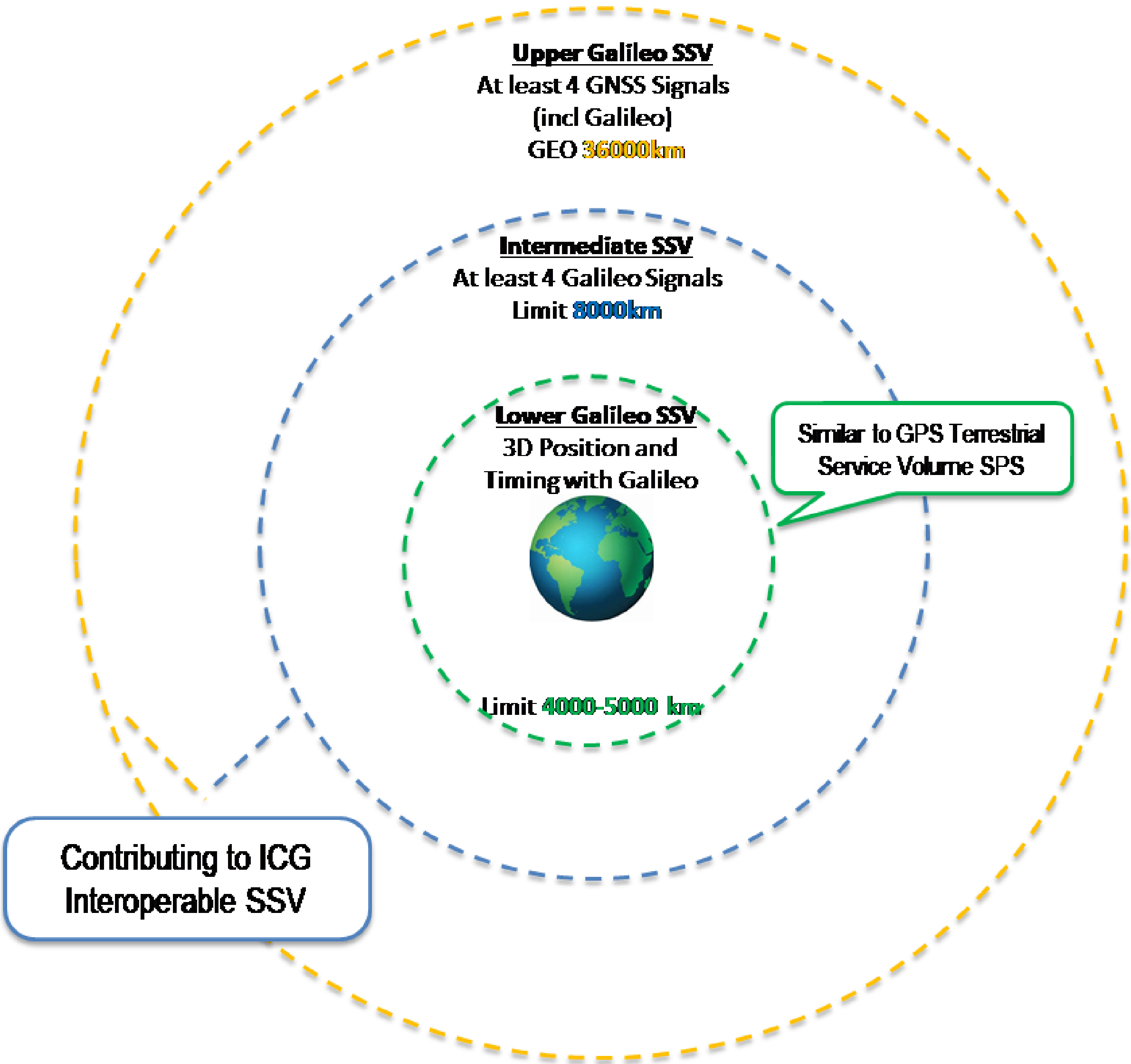
Although all space users operate in a similar environment – i.e. outer space – many variables come into play when identifying case-to-case GNSS requirements. A complex trade-off has indeed often to be found to comply with the targeted orbit, the spacecraft characteristics, the mission costs and the expected use of the GNSS technology aboard the satellite. Depending on the platform and the mission it has to accomplish, these different aspects have relative importance, driving the choices of the different user communities and the development of spaceborne GNSS receivers. The well proven benefits of GNSS-based solutions aboard spacecraft are quite diverse, ranging from the reduction of spacecraft's dependence on ground-based stations, undeniably improved navigation performances to indirect societal benefits (e.g. space-based public-safety situational awareness supported by the use of GNSS aboard the satellites). The security of space infrastructures has also become a driver for spaceborne developments, as the threat of offensive counterspace capabilities is growing.

In order to facilitate the development of GNSS capacities that would benefit as much as possible the different space user communities, International Committee on Global Navigation Satellite Systems (ICG) is putting a great deal of effort into creating a well-documented interoperable multi-GNSS SSV in which all existing global and regional navigation systems can be used together to provide improved capacities. The important work performed by the international space community in this regard reflects an increasing demand for spaceborne GNSS receivers among the users, urging both the upstream and downstream communities to design their products and services to support the simultaneous use of multiple GNSS constellations.

**Conclusion**

Given all of the above, the space environment can today be considered as a new high-potential playground for GNSS receivers, with both an increasing number of platforms to equip, and growing needs addressable by spaceborne GNSS-based solutions. Within this context, Galileo is an essential component and a key enabler of the emerging interoperable GNSS SSV. It has indeed to be underlined that the European system, in its 2nd Generation, will provide a service dedicated to Space users (see Figure 2).

Figure 2: Future Galileo (2nd Generation) Space Service Volume (source UCP Presentation of EC)




The European system offers significant advantages to the space users, whose applications varies a lot in terms of priority needs and accuracy requirements. Dual-frequency capacities guarantee better performances for the lower orbits, while the increase of the overall number of GNSS satellites allows to significantly improve availability for spacecrafts orbiting on MEO and beyond. Galileo high-accuracy and authentication features are also of great interest for space users. Getting down to position accuracy levels which you can otherwise only be achieved with POD processing on the ground – adding undesirable delays – HAS is indeed of high interest for many space applications and should be made as good as possible to achieve competitive advantage with Galileo. Driven by a rising interest in authentication for resilient GNSS-based navigation in space – in particular against jamming and spoofing – Galileo OS-NMA and CAS are attractive options to make navigation more robust and increase availability of a trusted navigation solution.

# 03 REFERENCE DOCUMENTS

| Ref. | Reference | Title | Date |
|---|---|---|---|
| [RD1] | EC GENESIS Project | R&D for a Galileo Space Service, Space User Requirements (SUR) | 2019 |
| [RD2] | UCP2020 Space Users MoM | MoM Space Users forum UCP 2020 | Jan. 2021 |
| [RD3] | GSA Market Report | GSA GNSS Market Report (Issue 6) | Oct. 2019 |
| [RD4] | GNSS Technology Report | GSA GNSS Technology Report (Issue 3) | Sept. 2020 |
| [RD5] | User Requirements Database | Excel User Requirements – UCP2020 Outcome | Mar. 2021 |
| [RD6] | COM(2016) 705 final | Space Strategy for EU | Oct. 2016 |
| [RD7] | ESA/C(2020)150 | 10th EU/ESA Space Council 2020 Resolution | Nov. 2020 |
| [RD8] | ST/SPACE/11 | Outer Space Treaty | 2002 Update |
| [RD9] | IADC space debris guidelines | IADC Space Debris Mitigation Guidelines | Sept. 2007 |
| [RD10] | ST/SPACE/75 | The Interoperable Global Navigation Satellite Systems Space Service Volume | 2018 |
| [RD11] | In-Orbit Servicing – know.space | In-Orbit Servicing: Dependencies with Space Surveillance and Tracking | March 2002 |
| [RD12] | Inside GNSS | Across the Lunar Landscape: Towards a Dedicated Lunar PNT System, Inside GNSS | Dec. 2020 |
| [RD13] | International Technical Symposium on Navigation and Timing (2016) | Space Applications of GNSS, Penina Axelrad, Colorado Centre for Astrodynamics Research (University of Colorado Boulder) | Nov. 2016 |
| [RD14] | Space, Cyber and Telecommunications Law Program Faculty Publication | Space Law and GNSS—A Look at the Legal Frameworks for “Outer Space” Frans G. von der Dunk University of Nebraska-Lincoln | May 2017 |
| [RD15] | OECD Science, Technology & Industry - Policy Papers | Space Sustainability – The Economics of Space Debris in Perspective | April 2020 |
| [RD16] | ENSPACE Project | H2020 ENSPACE project - https://cordis.europa.eu/project/id/776405/fr | May 2020 |

# 04 GNSS MARKET OVERVIEW AND TRENDS FOR SPACE USERS

## 4.1 MARKET EVOLUTION AND KEY TRENDS

The space sector is undergoing unprecedented transformation and development on a global scale. Major technology advancements, a new entrepreneurial spirit and a renewed policy focus have put the space sector under the spotlight on the global innovation stage.

### 4.1.1 FROM LANDSAT 4 TO THE NEW SPACE

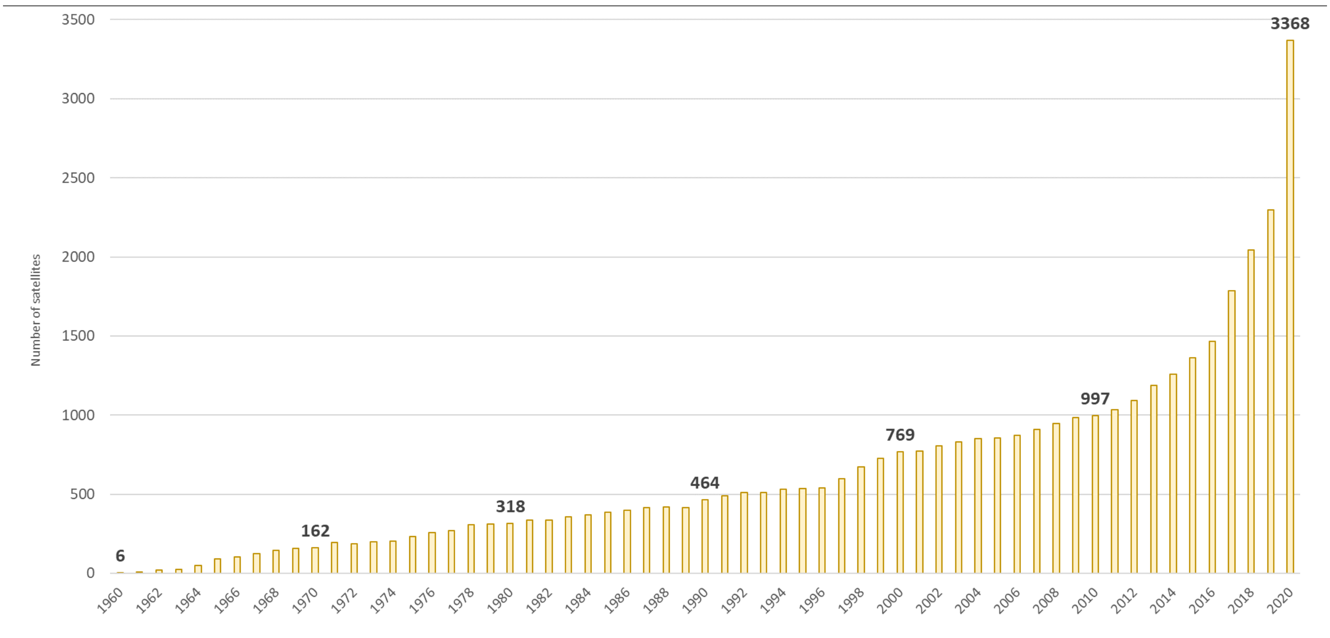
The space community started experimenting with spaceborne GNSS receivers very early during the deployment of the GPS network. In 1982, the first spaceborne GNSS receiver was indeed deployed in Landsat 4. Used to determine the spacecraft orbital position and readjust the on-board clock, this mission demonstrated early the feasibility of using GNSS for space navigation – despite the very few numbers of GPS satellites deployed back then (i.e. only 6 GPS Block 1 satellites). At that time, less than 350 active satellites were orbiting the Earth.

In less than 40 years, this number has grown tenfold (see Figure 3 below), real-time spacecraft navigation based on spaceborne GNSS receivers is becoming a common technique for LEO and GEO satellites, and new GNSS-based applications have emerged.

While the number of active satellites progressively increased until the beginning of the 21st century, the last decade has been witnessing an explosion of satellite industry, inevitably associated to a significant growth of the global space economy - growing at a CAGR of about 6% on the period 2010-2019[2].

One important contribution to this growth has obviously been the so-called “NewSpace” phenomenon: a series of technological and business model innovations 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.

**Figure 3: Evolution of the number of active satellites over [1980-2020][3]**




2 https://www.statista.com/statistics/897719/number-of-active-satellites-by-year/
3 Almost twice the 3% CAGR of the global economy (GDP growth).

### 4.1.2 GNSS IN THE NEW SPACE ERA

For a decade now, the space industry is experiencing an important paradigm shift. Characterised by the opening-up of the sector to non-governmental and more business-oriented actors, a disruptive commercially driven approach to space has emerged, based on innovative schemes and business models – for the benefit of scientists, businesses and the citizens.

Natural consequence of this increase and diversification of space users, the number of satellites orbiting the Earth has started to grow exponentially for a few years. Coupled with a permanent quest for smaller, lighter and lower-cost solutions, the need for spaceborne GNSS receivers has therefore become increasingly important, due to the financial and technical benefits it brings, interesting for both historical and emerging stakeholders (reduced number of instruments, reduce dependence on ground-based stations, improved navigation performances, etc.).

> The space sector is undergoing unprecedented transformation and development on a global scale.

**Democratisation & diversification of the space ecosystem**

More than just a trend, the NewSpace is a philosophy linked to the emergence of a private space industry and to the democratisation of space activities. Driven by unprecedented technological advancements such as artificial intelligence, digitalisation and miniaturisation, and a new entrepreneurial mindset, access to space has become significantly cheaper and faster – propelling space activities into the commercial realm.

Making space data the basis of high-value-added products, focusing on the needs of its end-users down on Earth, the space sector is today a cornerstone of our economic growth and societal well-being. In this new ecosystem, private actors play a different and more prominent role, both in the implementation of public programmes and the conduct of space business independently from governments.

**Digitalisation & new megaconstellations systems**

The NewSpace is characterised by a rapid diversification and commercialization of the space ecosystem, made possible through innovative business models and significant private capital investment. The development of Low Earth Orbits (LEO) megaconstellations projects has become a symbol of this new era, showcasing incredibly diverse commercial possibilities – particularly in Earth Observation but also in Satellite Communication for broadband connections or the Internet of Things (driven by the needs of global coverage and low latency). This dynamic is combined to an increasingly broader digitalisation of the global economy, in which innovative big data and geo-information business models are emerging. Direct consequence of this phenomenon, the LEO is expected to host an unprecedented number of satellites in the years to come. New business philosophies based on a rapid prototyping, production and deployment of small satellites (SmallSats) bring new challenges to the launch industry. Driving down the costs-to-orbit, particularly on LEO, this help create a virtuous circle that push the Information and Communication Technologies (ICT) sector and the space industry to converge more and more.

**New scalable business models**

The other transformation underlying the New Space dynamic lies in the advent of new scalable business models leading to a reduction in costs, shorter lifecycles and a bolder approach to risk taking in the space sector. Indeed, the NewSpace opens the space sector to an economical model where satellites are manufactured in batch, launches occur every month, parts & units are mass produced and processes are industrialized. Most importantly, in the age of (mega)-constellations, it is ok to fail.

New actors are however 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.

Most of the new small LEO satellites are coming out with a need for GNSS receivers. With a relatively short lifetime and therefore a higher replacement rate, these satellites stand as the key driver of the spaceborne receivers' market. The technical adaptations required to evolve in the space environment are moreover well-known and technically mastered in these low-altitude regions. The GNSS market for LEO satellites is therefore mature and several companies already propose off-the-shelf products (e.g. SSTL, GOMspace, Thales Alenia Space, etc.).

### 4.1.3 THE BROADER PICTURE

Although New Space is redefining the borders of the space industry, it's undeniably one aspect of a much broader and polymorph picture. New Space activities are indeed challenging but also complementing a wide range of already well-established space activities with a long heritage (e.g., military space activities, MSS/FSS communication satellites, launchers, traditional EO satellites, space exploration). Sustainability issues related to increasing activities in outer space is also a growing concern of the industry and another example of how complex the space industry has become. Necessarily linked to the NewSpace paradigm – which is one of the main reasons for the recent scaling-up of the space industry – this aspect cannot be attributed today to the technological and business model innovations which define the NewSpace (although space debris removal missions/techniques might sooner or later enter into this new commercial realm).

Moving every day, the space industry is today shaken-up by the NewSpace paradigm, arising from a favourable political, financial and technological context. This new era lays for sure the foundation of a future space application-based ecosystem, combining technological advances, private/public investments and strong involvement of the industries, entrusted with turnkey contracts.

## 4.2 MAIN MARKET PLAYERS

**GNSS Value Chain for Space Users**

The main stakeholders involved in the spaceborne GNSS-based market are depicted in the value chain below.

*Note: 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.*

| **GNSS Devices** Manufacturers | **Spacecraft** Manufacturers & Developers | **Spacecraft** Operators | Space-based **Service Providers** | **Final User** Communities |
|---|---|---|---|---|
| • Accord<br>• Airbus<br>• BAE Systems<br>• DLR<br>• General Dynamics<br>• Gomspace<br>• Green Lake Engineering<br>• Honeywell<br>• Hyperion<br>• Meisei Electric<br>• Moog Broad Reach<br>• Nec/Toshiba<br>• Newspace Systems<br>• Novatel<br>• Pumpkin<br>• Qascom<br>• RUAG<br>• Skytraq<br>• Spacemanic<br>• Space Quest<br>• Surrey Satellite Technlogy Ltd<br>• Syderal Swiss<br>• Syrlinks<br>• Thales Alenia Space<br>• Warspace<br>• ... | • Airbus<br>• Boeing<br>• OBH<br>• INVAP<br>• ISRO/Antrix<br>• Lockheed Martin<br>• Northrop Grumman<br>• Small Sats Developers (e.g. Pumpkin, Harris Corp., Isis, Astrocast, etc.)<br>• Mega-constellation procuring companies (e.g. OneWeb, SpaceX)<br>• SSL<br>• Thales Alenia Space<br>• Universities<br>• ... | • European Commission<br>• ESA (ESOC)<br>• NASA<br>• National Space Agencies (e.g. ASI, CNES, DLR)<br>• Universities<br>• Research Centres<br>• Private Companies (e.g. Intelsat, Eutelsat, SES, Telespazio)<br>• Non-profit Org. (e.g. Amsat)<br>• Defence Ministries<br>• National Space Agencies<br>• Armed Forces<br>• Defence Research And Innovation Agencies<br>• ... | • TV broadcast<br>• DHT Operators<br>• Communication Services Providers (incl. VSAT players)<br>• Commercial Teleport Operators<br>• EO-based private service providers<br>• GNSS-based private service providers<br>• Universities<br>• Research Centers<br>• EU (e.g. Copernicus)<br>• Governmental Institutions<br>• ... | • Public in General<br>• Earth Sciences Researches<br>• Territory Planners<br>• Environmental Monitoring<br>• Public Safety<br>• Infrastructure Operators<br>• Law Enforcement<br>• Emergency Services<br>• Internal Security<br>• Customs<br>• Military Forces (Land, Marine, Air)<br>• Geospatial Intelligence Agencies<br>• Governmental Institutions<br>• ... |

**Figure 4: GNSS value chain for Space Users**

**The role of the key players is as follows:**

*Chipset and GNSS Rx Manufacturers* includes 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 (e.g. Thales Alenia Space, General Dynamics) 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 both private and 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 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 branch of the market, ranging from well-established service providers (mainly in telecommunications) to small start-ups 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.

**A static picture of a dynamic ecosystem**

The value chain in Figure 4 offers an overview of the industry involved – directly or indirectly – into the space-borne GNSS receivers' market. It should however be kept in mind that such exercise only provides a static picture of an industry which has never been as dynamic as in the past few years. 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 enter the market, pushed by the NewSpace wave and pulled by increasing user needs and requirements all along the value chain.

The next decade is expected to follow this trend, with an important revamp of part of the market, due to the success/failure of some actors, the arrival of new players and the necessary adaptation of older stakeholders, fighting to keep their market shares and competing for new ones.


Credit: European Union, Copernicus Sentinel-2 imagery

## 4.3 MAIN USER GROUPS

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:

> The last decade has seen a significant number of actors enter the market, pushed by the NewSpace wave and pulled by increasing user needs and requirements all along the value chain.

- **Group 1:** Spacecraft integrators

The role of the spacecraft integrators is to implement the navigation function in the overall system. PNT is generally a function among others. 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 (see Section 4.4).

- **Group 2:** Spacecraft operators

Spacecraft operators have a very practical view on how GNSS is used aboard the spacecrafts they are responsible of. As described in Chapter 5, 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. These include mega-constellations procuring companies, who will drive the technology choice(s) in the area of GNSS receivers.

- **Group 3:** 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 (in space, in the atmosphere or down on Earth). Having different needs than classical GNSS users, their involvement in the definition of requirements for spaceborne GNSS receivers is essential.

- **Group 4:** 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.

In addition to these four categories of space users' communities, it is interesting to mention the following entities, whose undeniably have a role to play in the expression of functional and performances needs in terms of GNSS for space users.

- **United Nations Committee on the Peaceful Use of Outer Space** – They slowly defined long-term sustainability guidelines for operating in space. Their activities have a global impact, and even though their actions may be too slow for the trend of the small satellites launches in the next future, they remain an important actor of the space domain.

- **NASA** – Investing and planning to use GNSS both for launcher operations and for Moon orbital navigation (see Artemis missions 1-4 planned from 2021 to 2025).

- **ESA** – Is very active in the Collision Avoidance domain. Furthermore, ESA funded different studies for the development of a GNSS spaceborne platform (i.e. GomSpace).

- **UNOOSA** – Is active in defining the interoperable use of the available GNSS constellation for Space Service Volume.

- **EC and other institutional** – Could prepare, at European level, regulations for the use of EGNSS in Space.

## 4.4 GNSS LIMITATIONS IN THE SPACE DOMAIN

Spaceborne receivers are not significantly different from GNSS receivers used in other market segments down on Earth. They perform the same operations and provide the same PVT services as a classical receiver, but they have to respect some specific constraints due to the environment they are expected to evolve in.

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) and quickly changing satellite visibility. Larger bandwidths are therefore required to effectively track the signals. High altitude applications (above 8,000 km) are particularly challenging as they often require the reception of GNSS signals travelling from the other side of the Earth. There, spaceborne GNSS receivers generally have to cope with reduced signal power and visibility, potentially reduced pseudorange accuracy, less optimal geometric diversity and highly dynamic motion – affecting acquisition, tracking, time tagging and navigation data collection, and often requiring the ability to exploit GNSS signals first side lobes.

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. Finally, the mechanic endurance is also more requiring as space-borne receiver need to survive the extreme vibrations and noise inherent to a launch in a rocket.

In order to cope with such constraints, the ICG has put a great deal of effort into creating a well-documented interoperable multi-GNSS SSV in which all existing global and regional navigation systems can be used together to provide improved capacities to the space users. The important work performed by the international space community in this regard reflects an increasing demand for spaceborne GNSS receivers among the users, urging both the upstream and downstream communities to design their products and services to support the simultaneous use of multiple GNSS constellations.

## 4.5 POLICY AND REGULATORY FRAMEWORK

Outer space is defined as an area not subject to any territorial sovereignty, where the freedom of use and exploration is the baseline legal principle – codified in the 1967 Outer Space Treaty, to which all important space-faring nations are party. This is what is commonly labelled "Space Law," a body of rules addressing space activities (i.e. 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, the mitigation of space debris). But this does not constitute a proper legal framework for the use of any specific technologies in space – GNSS in this particular case.

Yet, the ongoing democratisation of the access to space is eventually pushing our society to consider the space environment as a commodity, at the same level as any other component of the global industrial infrastructure. Not reserved to a minority of stakeholders anymore, space is now a tool that can be used individually or in

Outer space is defined as an area not subject to any territorial sovereignty, where the freedom of use and exploration is the baseline legal principle – codified in the 1967 Outer Space Treaty, to which all important spacefaring nations are party.

*Space is now part of a global value chain that increasingly attracts new companies and entrepreneurs […] which are pushing the traditional boundaries in the space sector."*

*"This opens up new opportunities to develop innovative products, services and processes which can benefit industry in all Member States, creating new capacities and adding value in and outside the space sector."*

*"The Commission will support the competitiveness of the whole supply chain and actors fromindustry to research organisations."*

*"It will also foster the emergence of an entrepreneurial ecosystem, opening up new sources of financing, creating new business opportunities, and making sure this will benefit businesses in all Member States."*

combination of others, to the benefit of scientists, businesses or public bodies. This approach, which pushes daily towards the development of new space-based applications, therefore calls for an increasing number of spacecrafts and new performance needs – in which GNSS has a major role to play.

Recent institutional communications draw therefore the perimeter of what could be named a renewed European and global space industry – not that this defines any policy or regulatory structure, but it does demonstrate how the international community seek to frame the industry at different levels.  industry at different levels.

**EU Space Strategy 2016**

The international space context is evolving rapidly, with competition growing, space activities becoming increasingly commercial and a greater private sector involvement. Major technological shifts are reducing costs, challenging traditional models in the sector and digital technologies also brings significant opportunities – opening-up many business options for all EU countries. In this context, the space strategy for Europe was launched in October 2016, aiming to:

> *“NOTES that the global space economy is growing dynamically both in upstream and downstream sectors and exceeds the value of public programmes. It is driven by innovation and new market opportunities, thus increasingly turning the space sector into a mature and viable market with increasing spill over effects in other markets.”*
>
> *“HIGHLIGHTS the need for the space industry to make full use of the rapidly developing opportunities as well as for the public sector to promote market-based approaches for an increased efficiency in the space sector, in partnership with industry, to use the full market potential.”*

- bring tangible benefits to European citizens and companies
- foster a competitive and innovative European space sector
- reinforce the EU’s strategic autonomy
- strengthen the EU’s leadership on the global stage

The extracts above of the European Commission communication[3] demonstrate the dynamic in which the European space industry is developing.

**Galileo 2nd Generation (G2G) Implementing Act**

Additionally, in its 2nd Generation, Galileo will provide a Service for Space users, formalized through the corresponding Commission Implementing Decision[4]

**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.

The resolution[5] established as an outcome of the Council:

**Several countries adopting their own space policy**

Market and technology disruptions – in particular through the New Space – have also a significant impact on space policies at a European and national level. The evolving market calls indeed for moire agile policies, challenging existing frameworks on the interplay between public and private activities. Leading space countries are therefore reviewing their national space policies with a view to the market, while other countries which do not have a significant space industry so far are developing space policies in direct response to NewSpace.

3 COM(2016) 705 final
4 See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM%3AC%282020%298968&qid=1622716912827
5 ESA/C(2020)150

**Space Situational Awareness (SSA): safeguarding the space environment**

The diversification and the expansion of space users is of a great interest for the spaceborne GNSS receivers' market. Yet, the consequence it has on the space environment raise today the question of the awareness system and traffic management policies it requires. NewSpace activities could indeed overwhelm current space flight safety processes, putting at risk space infrastructure and human spaceflight.

Currently, no "highway code" has been established in outer space by the international community. Space traffic is mainly "ruled" by the Outer Space Treaty – establishing that no nation may claim sovereignty of outer space – and the IADC space debris guidelines – that aims at limiting the generation of space debris. With a situation evolving rapidly, agreements can be settled by the most relevant entities to limit the risks of collision, like the one between SpaceX and NASA, establishing a code of good practices with regards to Starlink satellites[6] . To anticipate a chaotic situation, part of the scientific community wants to set proper rules through the United Nations and its Committee on the Peaceful Uses of Outer Space (COPUOS). A text should be proposed in 2021 to address the topic, pending the support of enough national delegations.

The question of the role GNSS solutions could play in this long-lasting process is legitimate. Traffic management requires a good knowledge of each vehicle positioning and attitude, based on standardised and robust technological solutions. The development of spaceborne GNSS receivers and their deployment at a wider scale could therefore be one of the building blocks of future space regulations. As one leader of the global space industry, Europe has an important role to play in this context, as repeatedly underlined in the resolution adopted at the occasion of the EU/ESA Space Council 2020.

**Disclaimer:**

It should be noted that although interesting and constituting an important aspect of future space-related activities, Space Situational Awareness (SSA) and Space Traffic Management (STM) is considered as out of scope of the present user needs analysis. Its potential inclusion will be analysed in the next editions of the document.

6 The two main elements of this agreement are that (i) Starlink commit to manœuvre its satellites to avoid collision with the satellite of the American agency, and that (ii) if one of Starlink satellites get closer than 5 km from the International Space Station (ISS) the NASA should be warned to discuss avoidance manoeuvres one week in advance.

# 05 GNSS USER REQUIREMENTS ANALYSIS

## 5.1 GNSS LIMITATIONS IN THE SPACE DOMAIN

**Space users**

Space users are defined, in the context of this document, as the users of spacecraft operating within a defined Space Service Volume (SSV). The most common definition of the SSV is usually taken from the "The Interoperable Global Navigation Satellite Systems Space Service Volume" booklet of the UNOOSA – covering "the region of space extending from 3,000 to 36,000 km altitude, where terrestrial GNSS performances standards may not be applicable" [RD10].

On top of the areas covered by this definition, the present document also considers the lowest Low Earth Orbits (LEO) altitudes (i.e. 300 km) and the Moon Transfer Orbit (MTO) – covering therefore all the regions of space where spacecrafts can currently be reached by GNSS signals.

Space users are therefore considered as the spacecraft operating within this SSV. It refers to any vehicle or machine designed to fly in outer space, whatever its purpose(s) (e.g. telecommunication, Earth observation, meteorology, navigation, science development, space exploration) with a focus on artificial satellites operating on the Earth orbits. Launchers are not considered.

**Criteria/Performances relevant to users**

With growing needs addressable by spaceborne GNSS-based solutions, it is interesting to look into what are the achievable performances of the spaceborne GNSS receivers. As mentioned in Section 4.4, although they have to cope with a more stringent environment, spaceborne GNSS receivers are structured in a similar way to the one used for ground applications and are expected to compute the Position, Velocity and Time (PVT), by processing the raw measurements and data with the necessary navigation algorithms (including SPS, Kalman Filters etc.).

GNSS performances may be perceived according to several criteria, including several performance parameters or non-measurable parameters. Only criteria and performance parameters that are relevant for the analysis of Space user requirements have been retained, in particular accuracy, availability, continuity, resilience, integrity and power consumption – defined in Annex 1. Other criteria such as the need for multi-frequency and/or multi-constellation capabilities are mentioned where relevant.

The following sections aim at presenting the different identified GNSS-based space applications and to introduce the most relevant requirements for each of them.

## 5.2 GNSS-BASED SPACE APPLICATIONS

Based on the expected use of the GNSS receiver aboard the spacecraft, and the impact it can have on the associated performances and functional requirements, GNSS-based space applications can be segmented as follows (more details on each application are provided in the following sections):

**GNSS Receiver part of GNC subsystem**

- Precise Orbit Determination
- Attitude Determination
- Timing & Synchronisation

**GNSS Receiver acting or supporting Mission Payloads**

- Scientific & Operational Missions (e.g. Radio Occultation, Gravimetric measurements, Altimetry, time-stamping of EO data)
- Technology Demonstration (e.g. new reflectometry applications)

**Deep Space Applications**

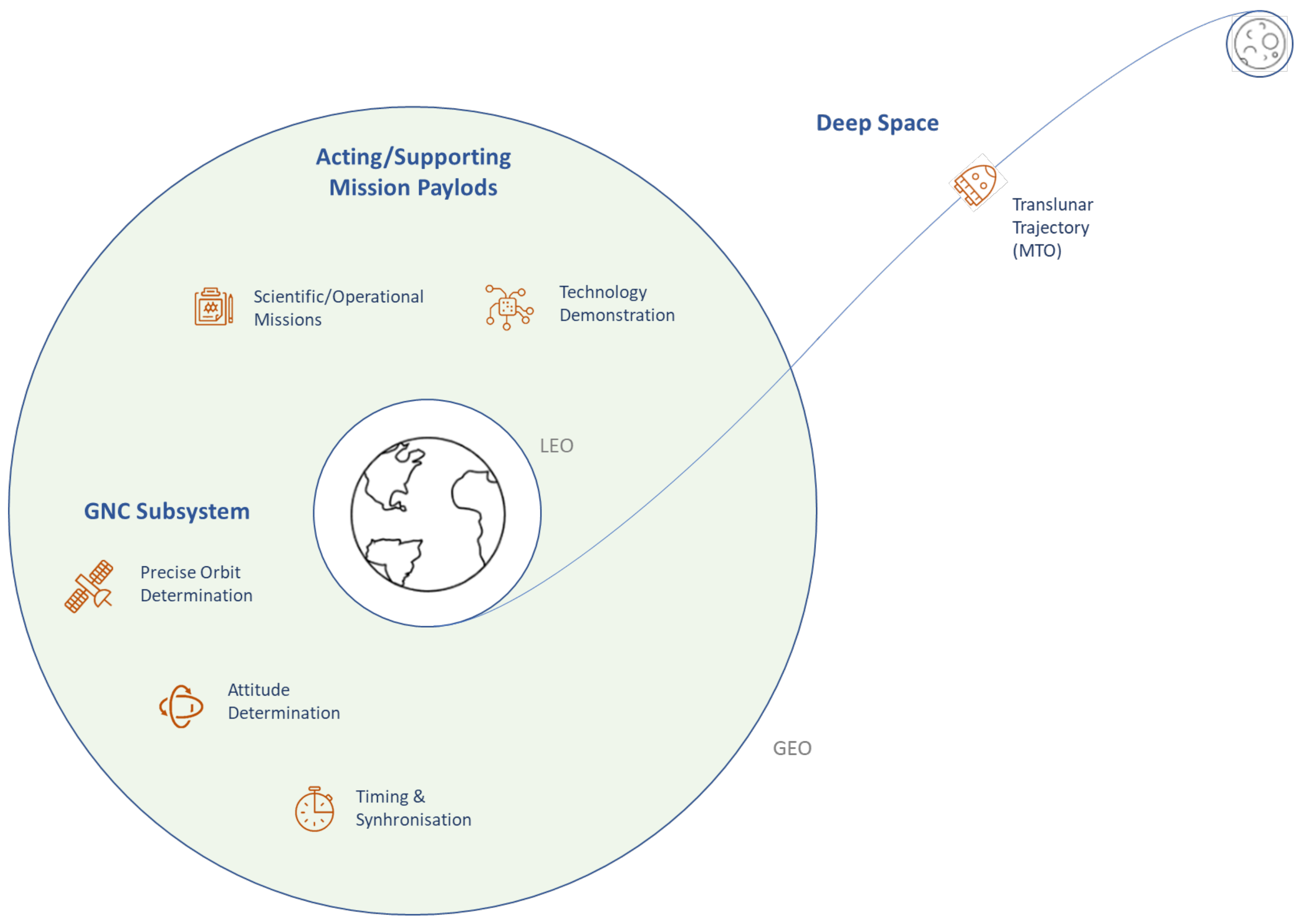
- Translunar Trajectory (i.e. Moon Transfer Orbit – MTO)

## 5.3 GNSS RECEIVERS SUPPORTING THE GNC SUBSYSTEM

The Guidance, Navigation and Control (GNC) subsystem of a 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.)

Figure 5: GNSS-based space applications




2. the **Control** of specific parameter (e.g. orbit characteristics, attitude/pointing direction, rotation/spin, etc...)

The GNSS receiver is only part of the Determination function, being a passive sensor but it plays often a key role thanks to its high performances. The following sub-functions have been identified for the role of GNSS inside the GNC subsystems:

- **Precise Orbit Determination** – To support the orbit control systems by providing real-time precise information on the orbital parameters (e.g. semi-major axis, eccentricity, etc.). Also supports other GNC functions like the Station Keeping and the Space traffic Management.
- **Attitude Determination** – To support precise pointing and to provide input information to the active attitude control systems
- **Timing & Synchronisation** – To synchronise the sensors and the actuators of the different GNC subsystem

The following table provides an overview of the functional needs for each one of the sub-functions.

(X) means that for some applications, authentication or integrity can be a need. For example, for GEO Station Keeping, Authentication capabilities can be an added-value because it is easier to be attacked with spoofing, being the satellite almost fixed with respect to the Earth motion, and it can have huge economic impacts (most

**Table 5-1: Functional User Needs for GNSS Receiver part of GNC subsystem**

| APPLICATIONS | Authentication | Coverage | Environment | Integrity | Time |
|---|---|---|---|---|---|
| Precise Orbit Determination | (X) | X | Full SSV | (X) | X |
| Attitude Determination | | X | Full SSV | | |
| Timing | | X | Full SSV | | X |

of the GEO satellites are commercial). Another example is the Collision Avoidance capability, as part of the Space Traffic Management function, where the need is to have Integrity from the Orbit Determination function due to the critical level of the required manoeuvre(s).

### 5.3.1 Precice Orbit Determination

The position estimation on-board the satellite can be estimated with two different methods and functions. The first one – the classical PVT estimation – provides a one-shot estimation of the position, velocity and time state vector. The second one – the Precise Orbit Determination (POD) – provides an estimation of the orbital parameters where the satellite actually is and with a much greater performance (1 order of magnitude better, or more) but usually the filters require a time for convergence (usually around some minutes). Precise Orbit Determination (POD) is therefore used to accurately estimate the position and velocity vectors of orbiting spacecraft, whose initial state is unknown. POD serves as the basis for several satellite applications, including science and navigation applications. 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 determination of precise orbital position and velocity vectors rely on advanced numerical methods based on data from GNSS signals.

Needs can be different depending on the orbit, the platform type (e.g. CubeSats) or the final objective. Such use of GNSS information can also be used to perform "Rendezvous & Docking" (i.e. two spacecraft meeting in space with the same velocity and joining into a complex – which is a key operational technology for complicated space missions such as assembling a space station or repairing a satellite in space) or "Formation Flying" (precise relative positioning of widely separated spacecrafts zipping through space at thousands of kilometres per hour). An increasing number of space missions indeed use a spacecraft formation or constellation in Low Earth Orbit (LEO) to meet certain scientific or operational objectives – for which precise orbit determination is a prerequisite. POD is also an important function in support to the GEO Station Keeping and the Space Traffic Management capabilities of a satellite. In the first case, GEO Station Keeping will rely on the POD capability to estimate accurately the orbital parameters to feed the Orbit Control function of the GNC subsystem to maintain the satellite in the correct position, in GEO, to provide the expected services with the expected service levels. For what concern the Space Traffic Management, the POD will provide the orbital information to the On-Board Computer that will analyse potential risks of collision with other in-orbit satellites to feed the Orbit Control function of the GNC for the execution of the Collision Avoidance manoeuvres.

The orbit accuracy achieved with the POD is typically between 0.1 mm/s to 1 mm/s for the velocity, but it must be performed only on ground in post-processing. Despite being in line with mission needs, the post-processing limitation is preventing its use for more advanced application that requires high accuracy in real-time, such as autonomous docking and rendezvous, and increased spacecraft autonomy. Although the use of high-quality dual-frequency GNSS receiver combined to the processing of ground-based data provides the best accuracy that can be achieved in precise orbit determination[7] and allows to consider some relative navigation applications, the main limitation for current on-board orbit determination algorithms is therefore the lack of precise ephemeris and clock products for the GNSS satellites in real-time [RD.1]. GNSS signals are however able to generate high accuracy ephemerides of GEO satellites equipped with a GNSS receiver, hence allowing station keeping manoeuvres which meet ITU requirements.

### 5.3.2 Attitude Determination

Space missions' success often rely on the pointing accuracy and the stability of its payloads. Being accurately aware of the vehicle's orientation in space allows to apply – if needed – the necessary torques to obtain the desired attitude. Furthermore, lot of small satellites rely on passive attitude control, but the attitude information is important for the mission, in support to other sensors

7 Martin Mur, 1997



like, 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.

Attitude determination with GNSS can be achieved in 2 different modes:

- With 1 single antenna – achievable performances are reduced and attitude is relevant only to the pointing direction of 1 axis (i.e. it is a 2D attitude information)
- With 4 planar antennas – achievable performances are higher and attitude information is complete (i.e. 3D)

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 don't 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.

### 5.3.3 Time & Synchronisation

The need for highly precise timing information is relevant in space both for data time stamping 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. The possibility to determine time with a high level of accuracy using GNSS receivers allows to be less dependent on very expensive on-board clocks.

Often used to provide Timing & Synchronisation services which rely on measuring the time of arrival of radio signals propagation, GNSS can therefore be used to provide a direct and accurate access to the Coordinated Universal Time (UTC), but also the synchronisation between receivers at different locations.

## 5.4 GNSS RECEIVERS ACTING OR SUPPORTING MISSION PAYLOADS

This segment groups all the type of receiver that are either directly used as sensors for scientific and commercial missions or supporting actively with their raw data the mission objective of other sensors. Both groups are mainly using the raw measurements of the GNSS signals, either exploiting the errors by correlating them with other physical characteristics or exploiting their time of reception after being reflected on Earth.

### 5.4.1 Scientific & Operational Missions

GNSS receivers are often used in support of specific missions. In the case of scientific missions, GNSS receivers can be used as a mission payload, providing input to study and model physical elements, through characteristics of the GNSS SIS measurements. Examples are the use of GNSS ranging data to study atmospheric conditions (i.e. Atmospheric Sounding and Radio Occultation missions) or the use of GNSS signals reflected from the Earth to perform Altimetry analyses. Other parameters such as the Ionospheric Total Electron Content (TEC) or physical forces (e.g. gravitational force, magnetic fields) can also be studied. In the case of operational missions, GNSS receivers can be used to support the acquisition of information for commercial purposes (e.g. use of precise GNSS position and time for taking and selling Earth Images/Observation Data).

Most of these missions will make use of the following GNSS products:

- Position information: A good 3D performance is needed. Science uses such as Earth's gravity field variations measurement, surface deformations, or sea surface height require that the accuracy of the orbit determination to be better than the measured variations themselves
- Attitude Information: Very important in order to reconstruct the atmosphere passage direction (i.e. for Atmospheric Sounding and Radio Occultation missions) or the reflected signal (i.e. for Altimetry missions).
- Timing Information: To time tag the measurements.
- Pseudorange measurements: To derive the missions' specific products.

### 5.4.2 Technology Demonstration

Using GNSS to demonstrate its scientific interest is the first step to assess its potential use with respect to other conventional technologies[8][9]. An example of this type of missions/uses is the so called GNSS Reflectometry (GNSS-R), which consists in making measurements from the reflections from the Earth of navigation signals from GNSS. The GNSS reflected signals from the ocean and land surface could determine the ocean height, ocean surface wind speed and wind direction, soil moisture, ice and snow thickness, vegetation, wetlands. Reflectometry missions generally require high-sensitivity equipment (i.e. multi-antenna, multi-constellation) to maximise the scientific return.

## 5.5 GNSS RECEIVERS FOR DEEP SPACE APPLICATIONS

Considering the attenuation of the GNSS signal with the travelled distance and also of the fact that as far as a satellite go from the Earth, he's receiving the GNSS signals from a narrow cone (i.e. with a bad geometry), the use of Satellite Navigation on orbits outside the Earth-Moon system is not an added value from the position point of view.

For the applications making use of GNSS outside the GEO orbits, the main differentiator is the use of Multi-Constellation due to the fact that the user shall receive the GNSS signals coming from the opposite side of the Earth and, therefore, with limited visibility and availability.

### 5.5.1 Translunar Trajectory[10]

The translunar trajectory or Moon Transfer Orbit (MTO) is one of the scenarios analysed by the ICG Working Group B (WG-B) in the context of their work on the "Enhancement of GNSS Performance, New Services and Capabilities". Simulations have indeed 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. Annex 3 present the results of the simulation carried out with the GNSS Outer Orbit Data Simulator (GOOD Sim) tool of WAY4WARD SRL, highlighting GNSS potential for translunar missions.

The MTO is currently still under study and no missions making use of GNSS have been launched at the moment. For this type of missions, the use of GNSS can be in support to the Precise Orbit Determination function and to the Timing and Synchronisation function of the satellite.

## 5.6 PROSPECTIVE GNSS USE IN SPACE

With the rapid development of space activities, new innovative mission concepts are made possible. The increasing number of operational GNSS capabilities and the its progressive penetration into the space domain suggest that spaceborne receiver will have an essential role to play in many of these future space activities (e.g. debris mitigation and removal, space tourism, space resources mining, etc.). Among these prospective space activities which could benefit from the use of GNSS, two are further explored below – the first one for its interesting market readiness, the second for the symbol it represents in the GNSS adoption by current and future space users.

**In-orbit servicing – Towards sustainability**

In-orbit satellite (IoS) servicing refers to the refuelling or the repairing of space satellites while in orbit. Although

8 E Cardellach, GNSS Transpolar Earth Reflectometry exploring System (G-TERN): Mission Concept
9 J. Innerkofler, Gottfried Kirchengast, Precise Orbit Determination for Climate Applications of GNSS Radio Occultation including Uncertainty Estimation
10 M. Manzano, J. Alegra et al, Use of Weak GNSS Signals in a Mission to the Moon

considered since the early days of spaceflights, the recent easier access to LEOs and space debris related issues tends to generate a renewed interest for the practice.

IoS has the potential to open-up new opportunities through satellite life extension, robotics and salvage, while also offering sustainability benefits through debris removal, proactive risk mitigation (for example, if a damaged satellite could be repaired or upgraded in space, it could remove collision risks and prevent further debris from aggregating) and material recycling over the longer term. While GNSS could be used as a mean of absolute (for the approach) and relative (for the connection) positioning, it is also suggested that in-orbits services may go beyond life extension, up to service enhancement, by providing additional capabilities to the client satellite (e.g. equip an already flying satellite with a new piece of hardware, such as a GNSS receiver).

**As far as the dark side of the Moon**

As explained in Section 5.1, the common characterization of an interoperable GNSS SSV – which is an important enabler for new missions and a key driver for new technological developments – is today limited to Earth orbits up to an altitude of 36,000 km (i.e. GEO). Yet, navigation is also a key technological enabler for cislunar missions (i.e. translunar trajectory and navigation on the non-occulted face of the Moon).

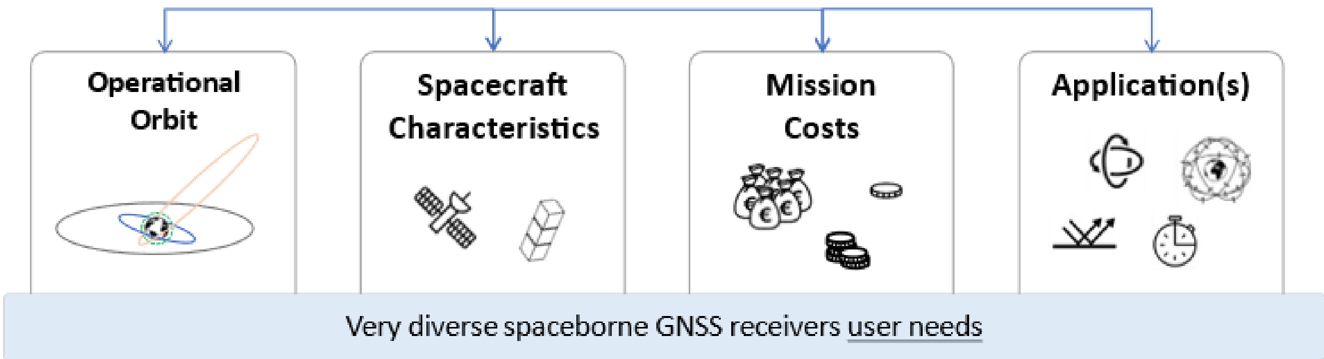
The international space community plans therefore today to extend GNSS PNT applications to the entire volume of our closest neighbour, the Moon - including its dark side. The lunar volume discovery, and all the moon exploration missions that define the emerging "lunar economy" share similar navigation needs to which GNSS could bring an answer. Different phase could be considered, starting with the use of the already existing Earth-GNSS constellations via high-sensitivity space receivers, leveraging the use of GNSS signals side lobes. Yet, such approach only allows to reach cislunar areas (not occulted by the Moon). Plus, if the objective is to get enough accuracy and availability to enable autonomous landing and rover guidance, Earth GNSS signals alone are not sufficient.

Going a step further, it is therefore possible to consider that Earth-GNSS constellations may be augmented with dedicated lunar orbiting satellites and lunar beacon ranging sources – a gradual deployment leading to a full autonomous lunar navigation system. Beyond the primary navigation purpose of such an ambitious system, any other GNSS-based applications could also be considered, in particular very interesting scientific ones, such as the study of lunar soil deformation based on GNSS-R.

## 5.7 DRIVERS FOR USER REQUIREMENTS

**A complex trade-off**

Although all space users operate in a similar environment – i.e. outer space – many variables come into play when identifying case-to-case GNSS requirements. Depending on their characteristics (i.e. mass, designed lifespan, mission budget) and the targeted orbit (synonym of variable geometrical constraints and signals availability – see Section4.4), spacecraft are not expected to be equipped with the same kind of spaceborne GNSS receivers. Large satellites can for example embark relatively heavy receivers (a few kg) while SmallSats want to avoid it. Similarly, most CubeSat missions cannot afford expensive pieces of equipment while long-term missions are ready to do so to guarantee the system robustness.




Whatever the mission type (i.e. Earth observation, telecommunication, technology development), it is the application for which the GNSS receiver is required that eventually sets the user needs. Whether it is for absolute positioning (i.e. attitude determination, GEO station keeping), for relative navigation (i.e. rendezvous and docking, formation flying) or for other types of applications (i.e. timing, synchronisation, radio occultation or reflectometry), the user priorities and the accuracy needs are different. In addition to all these orbital, weight, costs and applications considerations, the mission's specificities can also require the use of several receivers for redundancy, or specific security features.

**A plethora of benefits**

Whatever their mission type (e.g. telecommunication, Earth observation, scientific development, navigation), providing reliable real-time GNSS data to Earth-orbiting satellites bring anyway many financial, technical and societal benefits. Reducing the number of instruments required aboard (particularly expensive clocks) and reducing spacecraft's dependence on ground-based stations allows to make appreciable savings on mission costs. Spaceborne GNSS allows to benefit from improved navigation performances. Finally, the provision of a wealth of reliable EO data (whose capture may rely on GNSS-based solution – whether it is for navigation or measurement purposes) brings many societal benefits (e.g. smart farming, water management, renewable energy development, urban planning, public-safety situational awareness).

**Security**

Space security has become an increasingly salient policy issue. Over the last several years, there has been growing concern from multiple governments over the reliance on vulnerable space capabilities for national security, and the corresponding proliferation of offensive counterspace capabilities that could be used to disrupt, deny, degrade, or destroy space systems.

# 06 USER REQUIREMENTS SPECIFICATIONS

## 6.1 REQUIREMENTS FOR GNSS RECEIVER SUPPORTING THE GNC SUBSYSTEM

### 6.1.1 Precise Orbit Determination

**Table 2: Requirements for Precise Orbit Determination**

| Id | Description | Type | Source |
|---|---|---|---|
| EUSPA-MKD-USR-REQ-SPC-0301 | The PNT system shall provide a 3D accuracy of 3,5m (3 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0302 | The PNT system shall provide a 3D accuracy of 0,6m (95%) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0303 | The PNT system shall provide a 3D accuracy of 3,5m (95%) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0304 | The PNT system shall provide a 3D accuracy of 600m (3 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0305 | The PNT system shall provide a 3D accuracy of 350m (95%) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0306 | The PNT system shall provide a 3D accuracy of 100m (1 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0307 | The PNT system shall provide a 3D accuracy of 180m (95%) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0308 | The PNT system shall provide a 3D accuracy of 0.2m (3 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0309 | The PNT system shall provide a 3D accuracy of 0,15m (95%) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0310 | The PNT system shall provide a 3D accuracy of 3m (95%) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0311 | The PNT system shall provide a 3D velocity accuracy of 0.01m/s (1 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0312 | The PNT system shall provide a 3D velocity accuracy of 0.1m/s (1 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0313 | The PNT system shall provide a 3D velocity accuracy of 0.07m/s (1 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0314 | The PNT system shall provide a 3D velocity accuracy of 0.02m/s (1 sigma) or better | Performance (3D positioning) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0315 | The PNT system shall provide a 3D velocity accuracy of 0.01m/s (1 sigma) or better | Performance (3D positioning) | [RD1] |

It should also be noted that the table gathers 3D positioning and 3D velocity requirements of different order of magnitude. This is due to the different uses for which they have been expressed, since the Precise Orbit Determination function can be used in different contexts.

In this sense the most demanding needs for positioning are both EUSPA-MKD-USR-REQ-SPC-0308 (i.e. 20 cm - 3 sigma) and EUSPA-MKD-USR-REQ-SPC-0309 (i.e. the 15 cm - 95%). For the velocity, the most stringent requirement is the 0.01m/s (1 sigma) of the EUSPA-MKD-USR-REQ-SPC-0311.

On the other hand, from the point of view of a Constellation Service Provider the fulfilment of all user needs down to the most demanding ones would lead to a highly complicated and very expensive System. In that respect, the discussion held at the UCP2020 concluded that a requirement stringent enough to cover the majority of applications, yet ensuring an affordable System implementation would be a good compromise solution. This led to consider EUSPA-MKD-USR-REQ-SPC-0303 (i.e. 3,5m - 95%) as the key 3D positioning accuracy requirement, as it covers most of the applications considered for space users.

Furthermore, other requirements can be very demanding but they are not directly applicable to GNSS Receivers stand-alone. An example is the accuracy need for the Formation Flying that is very stringent (e.g. order of the decimetre) but it is usually achieved with the combined use of the GNSS observables from all the concerned satellites with the ranging information among them through the communication link, i.e. creating a mesh of the satellites group. This allows to achieve a higher accuracy in both the relative and absolute positioning of the satellites.

Finally, less stringent requirements (i.e. EUSPA-MKD-USR-REQ-SPC-0304 to EUSPA-MKD-USR-REQ-SPC-0307) were also expressed, calling for a 3D positioning accuracy ranging from 100 to 600m. These are present in the above list, although they are not considered as drivers of the spaceborne GNSS receivers development (i.e. similar performances achievable with other technologies).

### 6.1.2 Attitude Determination

No requirement has been discussed for Attitude Determination at the occasion of the last UCP (Dec. 2020). Yet, some needs have been identified and are reported in the table below for subsequent validation at the next UCP.

**Table 3: Requirements for Attitude Determination**

| Id | Description | Type | Source |
|---|---|---|---|
| EUSPA-MKD-USR-REQ-SPC-0401 (pending validation) | *The Attitude Determination system shall provide a pointing direction accuracy, with respect one axis, of 5 degrees (1 sigma) or better* | Performance (2D accuracy) | [RD16] |
| EUSPA-MKD-USR-REQ-SPC-0402 (pending validation) | *The Attitude Determination system shall provide an attitude information with an accuracy of 0.1 degree (1 sigma) or better in order to be used as backup sensor (*)* | Performance (3D accuracy) | - |

**(*) considering the use of other sensors for attitude determination (e.g. magnetometers, Sun sensors, star trackers, …), the minimum considerable accuracy required to be used as a backup is one order of magnitude worse than the primary sensor**

### 6.1.3 Timing & Synchronisation

**Table 4: Requirements for Timing & Synchronisation**

| Id | Description | Type | Source |
|---|---|---|---|
| EUSPA-MKD-USR-REQ-SPC-0501 | *The PNT system shall provide an accuracy down to 100 ns* | Performance (Timing) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0502 | *The PNT system shall provide direct and accurate access to UTC* | Functional (UTC) | [RD1] |

**Note: The requirements of timing are not very stringent (e.g. 100 ns) at this stage. Yet, in the near future, other type of applications may drive higher the demand of timing and synchronisation performances (e.g. formation flying).**

## 6.2 REQUIREMENTS FOR GNSS RECEIVER ACTING OR SUPPORTING MISSION PAYLOADS

### 6.2.1 Scientific & Operational Missions

**Table 5: Requirements for Scientific & Operational Missions**

| Id | Description | Type | Source |
|---|---|---|---|
| EUSPA-MKD-USR-REQ-SPC-0101 | *The PNT system shall provide a 3D accuracy of 0,4m (95% sphere) or better* | Performance (3D Accuracy) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0102 | *The PNT system shall use multi-frequency GNSS signals* | Functional (Multi-frequency) | [RD1] |
| EUSPA-MKD-USR-REQ-SPC-0104 | *The PNT system shall provide precise timing products in real-time* | Functional (Timing) | [RD2] |

### 6.2.2 Technology Demonstration (acting Mission Payload)

**Table 6: Requirements for Technology Demonstration**

| Id | Description | Type | Source |
|---|---|---|---|
| EUSPA-MKD-USR-REQ-SPC-0201 | *The PNT system shall use multi-frequency GNSS signals* | Functional (Multi-frequency) | [RD1] |

## 6.3 REQUIREMENTS FOR DEEP SPACE APPLICATIONS

### 6.3.1 Translunar Trajectory

At this stage, no specific requirements have been expressed with regard to this application.

# 07 ANNEXES

## A1.1 DEFINITION OF KEY GNSS PERFORMANCE PARAMETERS

This Annex provides a definition of the most commonly used GNSS performance parameters and is not specifically focusing on 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: the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to
- Overall: takes into account the receiver performance and the user's environment (for example if they are subject to shadowing).

**Accuracy:** the difference between a true and computed position (absolute positioning). This is expressed as the value within which a specified proportion of samples would fall if measured. Typical values for accuracy range from tens of meters to centimetres for 95% of samples. Accuracy is typically stated as 2D (horizontal), 3D (horizontal and height) or time.

**Continuity:** ability to provide the required performance during an operation without interruption once the operation has started. Continuity is usually expressed as the risk of a discontinuity and depends entirely on the timeframe of the application (e.g. an application that requires 10 minutes of uninterrupted service has a different continuity figure than one requiring two hours of uninterrupted service, even if using the same receiver and services). A typical value is 1x10-4 over the course of the procedure where the system is in use.

**Integrity:** the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver. This is usually expressed as the probability of a user being exposed to an error larger than alert limits without warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to the user are highly application dependent. For safety-of-life-critical applications such as passenger transportation, the "integrity concept" is generally mature, and integrity can be described by a set of precisely defined and measurable parameters. This is particularly true for civil aviation. For less critical or emerging applications, however, the situation is different, with an acknowledged need of integrity but no unified way of quantifying or satisfying it. Throughout this report, "integrity" 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 by other applications and sectors.

**Robustness** to spoofing and jamming: robustness is a qualitative, rather than quantitative, parameter that depends on the type of attack or interference the receiver is capable of mitigating. It can include authentication information to ensure users that the signal comes from a valid source (enabling sensitive applications).

Note: for some users, robustness may have a different meaning, such as the ability of the solution to respond following a severe shadowing event. For the purpose of this document, robustness is defined as the ability of the solution to mitigate interference or spoofing.

**Time To First Fix (TTFF):** a measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds. Activation means subtly different things depending on the status of the data the receiver has access to:

- Cold start: the receiver has no knowledge of the current situation and thus has to systematically search for and identify signals before processing them – a process that typically takes 15 minutes.
- Warm start: the receiver has estimates of the current situation – typically taking 45 seconds.
- Hot start: the receiver knows what the current situation is – typically taking 20 seconds.

**Latency:** the difference between the time the receiver estimates the position and the presentation of the position solution to the end user (i.e. the time taken to process a solution). Latency is usually not considered in positioning, as many applications operate in, effectively, real time. However, it is an important driver in the development of receivers. This is typically accounted for in a receiver but is a potential problem for integration (fusion) of multiple positioning solutions or for high dynamics mobiles.

**Power consumption:** 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 position. Typical values are in the order of tens of mW (for smartphone chipsets).

## A1.2 GNSS-BASED MOON TRANSFER ORBIT (MTO) SIMULATION

Figures 5 and 6 below present the result of the simulation carried out with the GNSS Outer Orbit Data Simulator (GOOD Sim) tool of WAY4WARD SRL, showing that in spite of a poor Geometrical Dilution Of Precision (GDOP), using two GNSS constellations (in this case Galileo and GPS) provides the availability of four SV in average.

The availability is therefore even increased in case of additional GNSS constellation used. In this context, the use of dual-frequency signals is not providing a significant added-value in the final performances.

**Figure 6: Geocentric Moon Transfer Orbit (MTO) trajectory (duration ~ 6 days)**

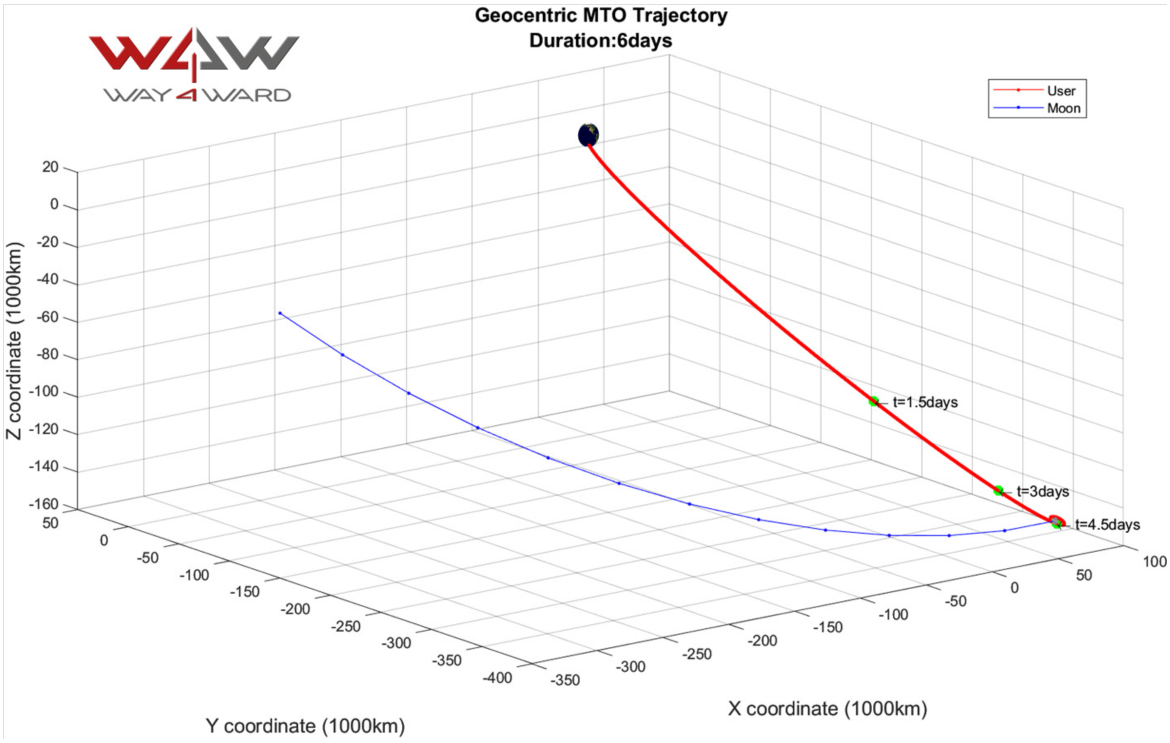
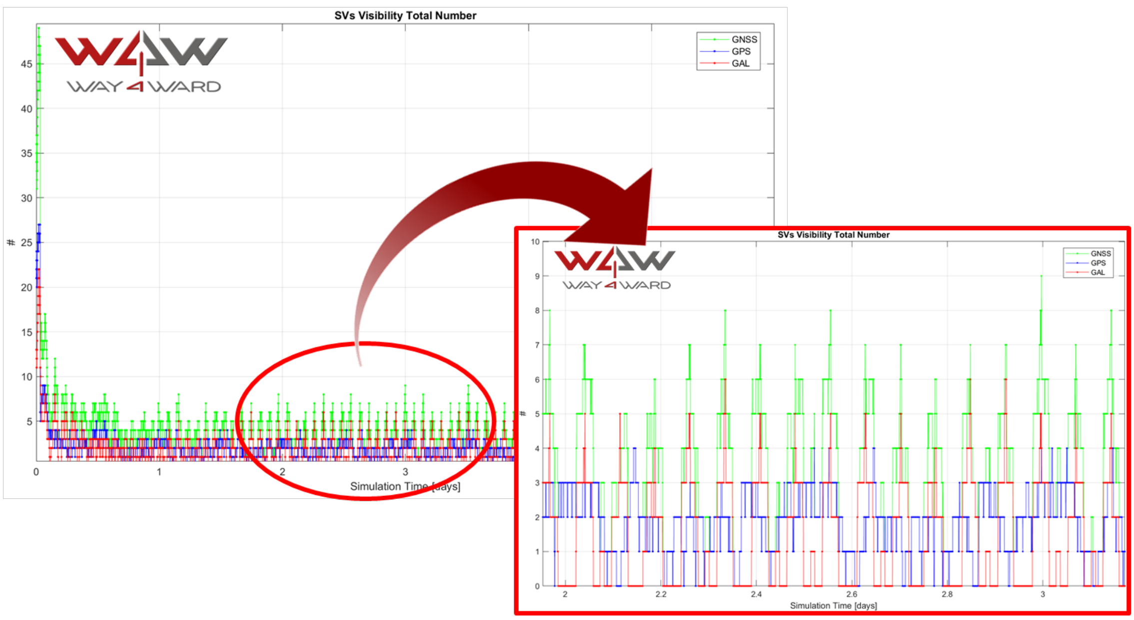



**Figure 7: GNSS electromagnetic visibility (1st + 2nd Lobe) in the Moon Transfer Orbit (MTO)**



# ANNEX 1.3 LIST OF ACRONYMS

| | |
|---|---|
| **AD** | Attitude Determination |
| **EO** | Earth Observation |
| **EUSPA** | European Union Agency for the Space Programme |
| **FSS** | Fixed Satellite Service |
| **GEO** | Geostationary Earth Orbit |
| **GNC** | Guidance Navigation and Control |
| **GNSS** | Global Navigation Satellite System |
| **GSA** | European GNSS Agency |
| **HEO** | Highly Elliptical Orbit |
| **IoS** | In-orbit Servicing |
| **LEO** | Low Earth Orbit |
| **MEO** | Medium Earth Orbit |
| **MKD** | Market Development (within EUSPA) |
| **MTO** | Moon Transfer Orbit |
| **MSS** | Mobile Satellite Service |
| **PNT** | Positioning, navigation, and timing |
| **POD** | Precise Orbit Determination |
| **SIS** | Signal in Space |
| **SME** | Small and Medium-sized Enterprise |
| **SSV** | Space Service Volume |
| **TEC** | Total Electron Content |
| **UCP** | User Consultation Platform |

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