Council of the
European Union

Brussels, 5 June 2023
(OR. en)

10259/23

ESPACE 27	**ENER 335**
RECH 274	**AGRI 301**
IND 288	**CSCGNSS 3**
EU-GNSS 16	**CSDP/PSDC 440**
TRANS 229	**CFSP/PESC 804**
AVIATION 116	**ENV 635**
MAR 84	**PECHE 231**
TELECOM 182	**FIN 599**

COVER NOTE

From:	Secretary-General of the European Commission, signed by Ms Martine DEPREZ, Director
date of receipt:	2 June 2023
To:	Ms Thérèse BLANCHET, Secretary-General of the Council of the European Union
No. Cion doc.:	SWD(2023) 203 final
Subject:	COMMISSION STAFF WORKING DOCUMENT European Radio Navigation Plan 2023

Delegations will find attached document SWD(2023) 203 final.

Encl.: SWD(2023) 203 final

EUROPEAN
COMMISSION

Brussels, 2.6.2023
SWD(2023) 203 final

PART 1/2

COMMISSION STAFF WORKING DOCUMENT

European Radio Navigation Plan 2023

PROGRAMME OF THE
EUROPEAN UNION

GALILEO EGNOS
NAVIGATION MADE IN EUROPE

EUROPEAN
RADIO NAVIGATION
PLAN 2023

This publication is a European Commission Staff Working Document, written by DG DEFIS in the cooperation with the Joint Research Centre (JRC), the European Commission's science and knowledge service.

The views expressed in this document are the views of the Commission Services and may not, in any circumstances, be regarded as representing the official position of the European Commission. The information in this document is intended for the consideration of the Members states and/or the entities dealing with PNT (Position, Navigation and Timing).

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The reuse policy of the European Commission is implemented by the Commission Decision 2011/833/EU of 12 December 2011 on the reuse of Commission documents (OJ L 330, 14.12.2011, p. 39). Except otherwise noted, the reuse of this document is authorised under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence (https://creativecommons.org/licenses/by/4.0/). This means that reuse is allowed provided appropriate credit is given and any changes are indicated. For any use or reproduction of photos or other material that is not owned by the EU, permission must be sought directly from the copyright holders.

All content © European Union, 2023 unless otherwise mentioned within the document.

Print Book ISBN: 978-92-68-00080-9 doi: 10.2889/559765
Electronic Book (PDF) ISBN: 978-92-68-00079-3 doi: 10.2889/245554
Catalogue Number: HV-09-23-074-EN-N (HV-09-23-074-EN-C)

How to cite this report: European Commission, 'European Radio Navigation Plan 2023', 2023, ISBN 978-92-68-00079-3, doi:10.2889/245554.

Contents

1 INTRODUCTION

Services dependent on **Position, Navigation and Timing (PNT[1])** have been since long an **engine for economic growth**. They also play a key role in the society and across multiple sectors and support critical infrastructures. Whilst the dependency on PNT services is growing in civil and commercial applications, they are also playing an increasing role in defence, security, and safety of life operations.

PNT services are mainly based today on radio navigation systems and notably on the services provided by the **Global Navigation Satellite Systems (GNSS**). The use of GNSS has spread across many sectors, grounded on the evolution of the existing constellations and the appearance of new ones. Today, around 10% of the European Union (EU) GDP relies on the use of **GNSS services**, and the trends suggest that this will continue increasing. In all, there is significant potential for industry in and across many sectors to better exploit GNSS services and to avail of, and benefit from, the superior performance that GNSS offers.

PNT terrestrial systems have played for many years a key role either in combination with, or independently from GNSS. However, the uptake and evolution of GNSS solutions opens the possibility to decommission or **rationalise some terrestrial-based PNT systems**. This would permit cost savings on the installation, operation, and maintenance of the terrestrial infrastructure. It would also release the associated electromagnetic radio spectrum.

GNSS signals, however, are vulnerable to natural and artificial interference, and to intentional attacks like jamming and spoofing. Thus, for critical applications or critical infrastructure protection, it is broadly accepted that GNSS, even in a multi-constellation and multi-frequency environment, should not be the unique source of PNT information. For those applications, an **alternative PNT** solution (back-up but also complementary) should be developed and maintained, not necessarily based on radio frequency technologies.

In the European Union (EU), the European Commission (EC) manages the **European Global Navigation Satellite Systems (EGNSS)** Galileo and EGNOS. **Galileo** is EU's autonomous GNSS under civil control, offering state-of-the-art PNT services to users worldwide. **European Geostationary Navigation Overlay System (EGNOS)** is the EU augmentation system that improves (accuracy, integrity) existing navigation signals generated from Global Positioning System (GPS), and Galileo in the future. EGNOS enables the use of GNSS signals in safety-of-life applications, most notably in the aviation sector.

The **use of GNSS services is multiple**. To name a few, GNSS services are currently used to improve traffic flows and vehicle efficiency, help track parcels and shipments by providing added-value logistic solutions, facilitate civil protection operations in harsh environments, speed up rescue operations and provide critical tools to coastguard and border control authorities. GNSS is also a formidable instrument for the timestamping required in financial transactions, scientific research in areas like meteorology, atmospheric science, geophysics, and geodesy and for key critical economic activities.

Although the use of GNSS is increasing, the services offered by **GNSS** are **not yet fully exploited** in all market sectors. Furthermore, the use of autonomous, unmanned and remotely controlled vehicles is

---

[1] Acronyms are defined in **Error! Reference source not found.**, including those in figures and tables.

experiencing an exponential growth. Considering the role that GNSS services can play in all these market sectors, there is a clear need for the EU to take full advantage of the benefits that Galileo and EGNOS can offer and facilitate their adoption sector by sector.

1.1 Context of the European Radio Navigation Plan (ERNP)

The context at the time of writing this version of the European Radio Navigation Plan (ERNP) – year 2023 – plays a significant role in the ambition, the scope, and the objectives of this version of the ERNP. The major contextual elements for this edition of the ERNP are the following ones:

1. The **Space Strategy for Europe**, published in 2016, requested the European Commission to 'release a European radio navigation plan to facilitate the introduction of global navigation satellite system applications in sectoral policies'. On this basis, a first version of the ERNP was published in 2018.

   The current document, which is the second version of the ERNP, still has as main objective to 'facilitate the introduction of Galileo and EGNOS applications in different market domains'.

2. The **European Court of Auditors** issued in **2021** a **Special Report** on the EU Space programmes Galileo and Copernicus and the need to further boost the update of their data and services.

   The recommendation 4c on the better use the regulatory framework to support the uptake of EU space services, requests the European Commission 'to define time schedules for each relevant market segment, where regulation or standardisation can facilitate the use of Galileo and closely monitor them'. Hence, the objective of this version of the ERNP is to address this recommendation.

3. There is an **increased importance of PNT services, mainly based on GNSS**, for the economy and society. This increased importance is not only related to positioning and navigation services but also to timing services (key for finance, power grids, communication, etc). This trend will continue to grow in the following years.

   Space services and data are an **important enabler for the digital transformation** of the economy and society and empower digital innovations such as autonomous vehicles, smart solutions and 5G/6G wireless telecommunication networks.

4. **There is an increased number of disruptions of GNSS services** due to the relatively low power of the GNSS signals. Simple low-cost devices can cause deliberate interference to frequencies used by GNSS with the intention to disrupt GNSS signal reception (i.e., 'jamming') and jammers with much higher power that can impact on a much wider area. GNSS services can also be 'spoofed' with false information leading to errors in the PNT solution. Finally, GNSS services may suffer from severe degradation of performance due to space weather events or system failures.

   At the same time, there is **increased awareness of the GNSS interference and measures to improve the resilience of GNSS signals are proposed** (e.g., European Union and United States cooperation on satellite navigation with focus on service resilience).

   This version of the ERNP will discuss both how GNSS services are becoming more resilient (i.e., Galileo new services including authentication) and how other technologies could deliver PNT services even upon GNSS disruptions.

5. **PNT services are fundamental for emerging applications and some emerging technology will deliver PNT services too.**

   Examples of the former is the use of **GNSS in the positioning** of Low Earth Orbit (LEO) multi-constellations (required to control the constellation) or space objects (required for a Space Traffic Management system) or the use of **GNSS for** 5G and 6G technologies **sub-microsecond** worldwide **timing accuracies**. Examples of the latter are **LEO constellations aiming to deliver PNT** services and future capabilities of **5G and 6G networks targeting the delivery of accurate PNT** services.

   This version of the ERNP will discuss the emerging technology that is related to PNT services.

6. **Strategic PNT autonomy**: Strategic autonomy is a policy objective of the European Union under the von der Leyen Commission. The EU is taking steps to reinforce the European strategic autonomy in various domains such as the EU's economic and financial strategic autonomy or the Strategic Compass for Security and Defence. The Strategic Compass calls for the adoption, by the end of 2023, of an **EU Space Strategy for security and defence**.

7. Last but not least, the **EU Space Programme Regulation (EU) 2021/696** defining the services of the European satellite navigation systems and the **European Commission's Priorities for 2019-2024** where PNT services and GNSS in particular contribute majorly (e.g., European Green Deal, Europe fit for the digital age).

1.2 Purpose of the ERNP

Considering the above contextual information, the purpose of this edition of the ERNP is the following:

1. **Provide relevant information on PNT systems and services**, their use, typical performance, strengths, weaknesses, developments, trends, challenges, opportunities, etc.

   The intention of this version of the ERNP is to provide synthetic and summarised information of PNT systems and services and to further refer to public sources for more detailed information.

2. **Facilitate the uptake of the European GNSS (Galileo and EGNOS) services** by:
   - Providing detailed information on EGNSS (European GNSS) current and future services and their added value with respect to other PNT/GNSS services.
   - Recommending, per each sector, actions to be implemented at EU level for the uptake of EGNSS in the various market domains (e.g., legislation, standards).

3. Raise awareness and recommend actions to be taken to **increase the resilience of PNT services in the EU.**

1.3 Scope of the ERNP

The following aspects are within the scope of the current edition of the ERNP:

1. Most relevant **space based and terrestrial PNT** systems and services, including those which are not radio frequency based.
2. **Current use and expected future-use** of the PNT system and services.

3. **Emerging PNT systems and services** (LEO, 5G, sensor-fusion, etc.) as far as they are to play a major role on PNT.

It is not in the scope of the current ERNP version to describe the systems and technologies which are not used primarily for positioning, navigation, or timing, such as for instance surveillance systems (e.g., radars, cameras).

1.4 Objectives of the ERNP

Considering the context, purpose and scope presented in the previous sections, the current version of the ERNP has the following objectives:

1. **Introduce PNT** and highlight its important **role in society,** the **economic benefits** it creates and the **potential impact of PNT disruptions** if/when they exist, notably on Critical Infrastructure.
2. Provide an overview on **PNT user needs** in the various market sectors.
3. Explain the **challenges of PNT/GNSS** and the **trends and opportunities** for PNT/GNSS services**.**
4. Provide an overview of the **major PNT systems** and services, including conventional, GNSS and emerging systems, with their current and future use and typical performance, developments, strengths, and weaknesses. Provide information on the **interoperability and compatibility** of PNT systems and services.
5. Provide an overview on the relevant **international policies** related to PNT.
6. Provide **detailed information of the European GNSS services** (Galileo and EGNOS) highlighting their added value with respect to other GNSS services and including future planned services.
7. Explain the **European Union policies** related to PNT, including the on-going activities to facilitate the introduction of the European GNSS in EU policies.
8. Recommend, per market sector and when relevant:
    - **Actions to facilitate the introduction of EGNSS**, including Regulations and Standards.
    - **Actions to increase the resilience of PNT services**.
9. Provide a **medium-term vision** on how PNT should evolve in the European Union.

1.5 Structure of the ERNP

The current version of the ERNP will be structured as follows:

- Section 1 covers the Introduction and includes the context, purpose, scope, the objectives, and the structure of the document.
- Section 2 discusses the PNT Landscape covering the objectives 1 to 5 and includes an introduction to PNT, its role in society, economic benefits, PNT user needs per market segment, challenges, trends and opportunities, the overview of the major PNT systems and services, their interoperability and compatibility and the main international PNT policies.
- Section 3 discusses the EU PNT covering the objectives 6 to 8 and includes the EU Space Programme, the main services provided by the European GNSS systems Galileo and EGNOS and the current EU policies related to PNT per market segment together with the additional actions that would facilitate the uptake of Galileo and EGNOS services and/or increase the resilience of PNT services. It also includes the EU cooperation activities on GNSS.

- Section 4 provides the medium-term view of the EU PNT covering the objective 9.
- The various appendixes provide detailed information of the various aspects described in the document.

1.6 Comments to the ERNP

Comments to the ERNP are welcome and will be considered for the next update of the document: DEFIS-GNSS-ERNP@ec.europa.eu.

2 PNT LANDSCAPE

This section discusses the PNT landscape and covers the objectives 1 to 5 introduced in section 1.4. It allows the reader to get relevant summary information on PNT systems, services, user needs, challenges, trends, and opportunities and PNT international policies. It sets the basis for the following section where the EU PNT will be discussed.

The section will:

- Introduce PNT (section 2.1).
- Describe the role of PNT / GNSS in society (section 2.2).
- Assess the economic benefits of PNT / GNSS (section 2.3).
- Summarise user needs per market segment (section 2.4).
- Describe the PNT / GNSS challenges (section 2.5).
- Describe the PNT / GNSS trends and opportunities (section 2.6).
- Summarise the major PNT systems and services (section 2.7).
- Describe the importance of interoperability and compatibility (section 2.8).
- Summarise the major International PNT policies (section 2.9).

The section intends to provide an overview of the above-mentioned topics while providing the public references for further detailed information.

2.1 Introduction to PNT

PNT (Position, Navigation and Time) describes a combination of three distinct yet integral capabilities:

- Positioning is the ability to determine one's location and orientation in two or three dimensions. This position is referenced to local or, most commonly, a global coordinate system such as Galileo Terrestrial Reference Frame (GTRF), European Terrestrial Reference Frame (ETRF) or International Terrestrial Reference Frame (ITRF).
- Navigation is the ability to determine a path between current and desired position (relative or absolute), as well as navigate this path by applying corrections to course, orientation, and speed.
- Timing is the ability to acquire and maintain time either locally or globally (for example Coordinated Universal Time, or UTC). This also includes time transfer service.

The main feature of the modern PNT is the ability to **accurately determine and maintain both position and time in the global reference frame** (GTRF, ETRF, ITRF etc. for position and UTC for timing), anywhere in the world, noting that different PNT systems will have different geographical ranges, from global to regional and local.

Throughout the document, the following key concepts will be used:

- **User performance indicators** typically used when assessing PNT services performance:
    - 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% to 99.9%.
    - Accuracy: the difference between true and computed user solution (for position or time).
    - Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver.
    - Continuity: the ability to provide the required performances during an operation without interruption once the operation has started.
- **Other relevant performance indicators** for PNT receivers:
    - 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.
    - Robustness to spoofing and jamming: a qualitative rather than quantitative parameter that depends on the type of attack or interference the receiver is capable of mitigating.
    - Authentication: the ability of the system to assure the users that they are utilising signals and/or data from a trustworthy source, and thus protecting sensitive applications from spoofing threats.

2.2 Role of PNT in society

Facing global challenges such as the digital revolution, climate change and global pandemics, the economy and society relies more than ever on innovative solutions which can deal with big data, mitigate natural and human-made disasters and diseases, and strengthen a global supply chain that underpins our daily lives. **PNT and GNSS play a vital role in contributing to these innovative solutions** through thousands of applications that are emerging or already in use by citizens, governments, international organisations, NGOs, industry, academia and researchers around the world (European Union Agency for the Space Programme – EUSPA EO and GNSS Market Report 2022). The overall installed base of GNSS devices will grow from 6.5 billion units in 2021 to 10.6 billion units in 2031. The lion's share of the installed base is dominated by the Consumer Solutions.

Apart from those market driven forces, the environment sustainability plays an important role. The **European Green Deal** aims for a climate-resilient society in an age when some European economies are still heavily reliant on coal and fossil fuels. This initiative is considered one of the most consequential legislative efforts in the history of the European Union, comprehensive of every aspect of society and the economy and across all policy areas. Arguably the best-known objective of the European Green Deal consists of cutting carbon dioxide net emissions to zero by 2050, and already by 55% by 2030 (compared to 1990 levels). And while Europe has already cut a quarter of its emissions since the 1990s, this is still not enough to reach the stated 2030 and the 2050 objectives. **EU Space data and services contribute to the European Green Deal** through positioning, navigation and timing used, for instance, in smart farming, as well as for reduction of road, maritime and aviation emissions through route optimisation. Moreover, the EU provide funding and support for entrepreneurs using Copernicus and Galileo data, which predominantly results in financing 'green' applications, while stimulating the relevant markets.

Another driving factor of our society is the **digital transformation**, which Europe has envisaged within the 2030 timeframe. **Spatial information is profiling as an integrator**, paving the way for a common, open, and innovative digital infrastructure, rather than a simple point location enabler for applications. Artificial Intelligence (AI)-based analysis of big-data promises to revolutionise the use of satellite data for tasks that include quantification of global urbanisation, the nourishment of the world's population, as well as improving the management of natural hazards or pandemics.

More satellites and more frequencies will bring a wealth of advantages. Dual frequency is already required for carrier phase-based algorithms (Real Time Kinematic (RTK), Precise Point Positioning (PPP) and PPP-RTK) and triple frequency can further improve the performance of the phase ambiguity resolution algorithms in terms of the maximum separation from a reference station (for RTK and Network RTK), the reliability of the solution and the time required to obtain and validate it).

However, **cyberattacks, including Radio Frequency Interference (RFI) of GNSS signals** is one of the most relevant aspects to be considered. GNSS jamming incidents are reported in increasing numbers, most of them caused by so-called 'privacy protection devices' (illegal in most countries). GNSS spoofing incidents are also increasing, though less frequently. GNSS services should be able to response to these threats by including monitoring and **authentication capabilities** as a necessary building block of the overall application security, without prejudice to other techniques.

Finally, it is fundamental to consider PNT services through the system of systems **'sensor fusion'** perspective, the paradigm for autonomous driving and other demanding applications, increasing integrity, availably and accuracy of the service. Indeed, future evolution is expected to take place at the level of effectiveness of sensor fusion techniques. The vision is not to have one technology as the 'primary' means of PNT but rather a combination of all the relevant existing PNT technologies.

2.3 Economic benefits of PNT / GNSS

PNT and GNSS have become a ubiquitous utility for millions of people across Europe. Many aspects of our daily lives are facilitated by invisible GNSS signals from space – from checking the status of our early morning commute to watching our favourite TV shows before bed.

EUSPA analysis on the socio-economic benefits provided by GNSS[2] shows **total GNSS economic benefits of total EUR 2 trillion** in European territory (defined as the EU27 plus the United Kingdom (UK), Norway, and Switzerland) over the period of analysis (1999-2027). In addition to this, over the same period more than 100 000 high-paying, highly skilled jobs were also estimated to be attributable to GNSS across Europe in the downstream and upstream industries.

Reports focusing on the United Kingdom and United States (US) estimate both the economic benefits produced by GNSS in the relevant economy and the economic losses expected as a result of a temporary outage of GNSS. For loss estimates, the relevant counterfactual in each application is technology that is available for immediate deployment in the event of an outage (rather than against any theoretically feasible technology, as in the case of benefits), meaning loss and benefit estimates vary significantly. The results of the UK, US, and EU studies are summarised in the next table.

Table 1 –Summary of reported economic benefits and losses

Study focus	Economic benefits (annual)	Economic loss	Economic loss (per day)
UK	GBP 6.7 billion	GBP 5.2 billion (5 days)	GBP 1.0 billion
US	USD 300 billion	USD 30.3 billion (30 days)	USD 1.0 billion
Europe	EUR 69.0 billion	Not Available	Not Available

The discrepancies in the reported values suggest that **careful analysis** of the European states would be required **before extending or generalising the findings to the European context**. Some of the important differences that would have to be considered include geographical differences such as population density, cultural differences reflected in population attitudes and legal frameworks, study methodology differences such as scope of analysis (i.e., economic sectors considered, or satellite constellations included in analysis) and choice of counterfactuals, infrastructure differences with implications for resilience or available technology and time period differences that impact estimated total impacts and averaged 'daily' values.

---

[2] To assess the economic benefits generated by GNSS in Europe, the study compared the quality of services enabled by GNSS with a counterfactual case where the next-best technologically feasible solution had been developed instead. In many cases these hypothetical solutions have not actually been developed at the required scale – due in large part to the low cost, high performance, and wide availability of GNSS

It is important to note that the RAND report argues that **cost of GNSS outage might be overstated**, possibly by orders of magnitude, as for many industries backups are already operational.

In summary and despite the differences and opinions reported above, we can affirm that GNSS provides **annually hundreds of billions of euro** to the worldwide **wealth**, while a few-days GNSS outage could imply an **economic loss** of up to several **billions of euro per day** worldwide.

2.4 PNT user needs

The user needs for PNT services are widely described in the **EUSPA user needs and requirements reports**. These reports include a market overview, trends, user requirements analysis and specifications for various market segments.

In addition, the **EUSPA EO and GNSS Market Report 2022** provides a detailed description of the use of PNT/GNSS services in various market domains and an overview of the main applications.

Other non-EU documents provide similar information, such as the US report Economic Benefits of the Global Positioning System (GPS) and the US Federal Radionavigation Plan.

Figure 1 provides an overview of the role and trend of GNSS across various market segments.

Agriculture – New technologies are pushing the Agriculture sector to new frontiers. GNSS is considered a key driver and enabler for these evolutions, ranging from traditional farming applications to Internet-of-Things, blockchain, Agri-fin tech and value chain management. GNSS-enabled livestock wearables are emerging as an exciting trend which is improving animal welfare.

Aviation and Drones – Global air traffic took a huge hit due to COVID-19 – airlines responded with consolidation of fleets, and older aircraft prioritised for retirement. Meanwhile, standards evolution in navigation and surveillance presses ahead, enhanced by growing demand from increasingly sophisticated drone operations.

Biodiversity, Ecosystems and Natural Capital – In the domain of biodiversity, ecosystems and natural capital, GNSS-beacons are used to geo-locate animals for the purposes of monitoring migrations, habitats, and behaviours. These are becoming more accurate and additional biodiversity applications are emerging (e.g. botanical mapping).

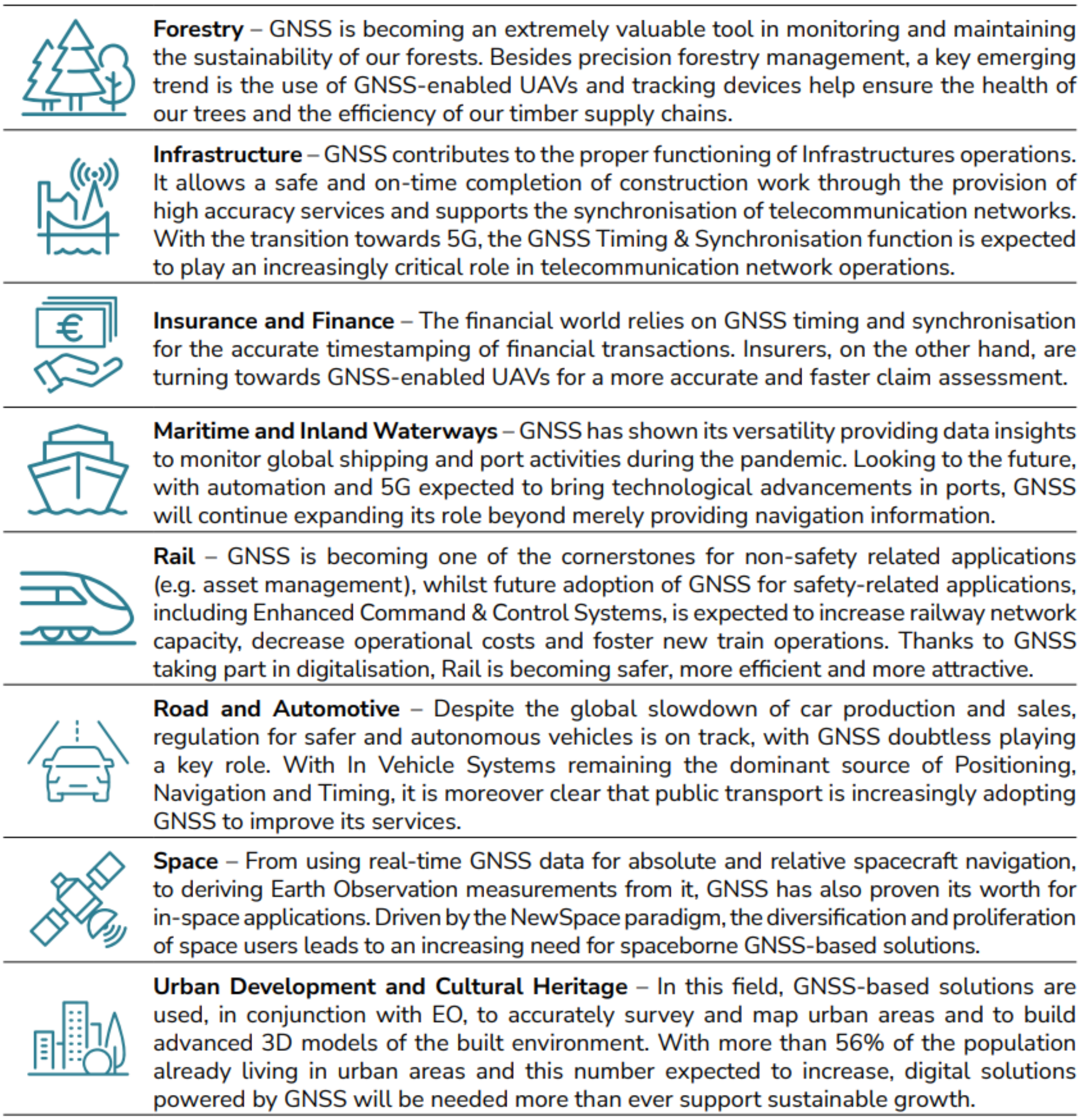
Climate Services – GNSS has limited but important application in the climate services domain. The technology supports a range of geodetic applications that measure properties of the earth (magnetic field, atmosphere) with direct impact on the Earth's climate. GNSS is expected to have an increasing role in the growing market of climate modelling.

Consumer Solutions, Tourism and Health – GNSS finds increasing use in facilitating our daily lives. From context-aware apps monitoring peak visit times to contactless deliveries and personal fitness apps (powered by wearable devices), navigation and positioning information plays a vital role.

Emergency Management and Humanitarian Aid – Estimated to save 2,000 lives a year, the new MEOSAR system of the GNSS-based COSPAS-SARSAT programme relies on the proper use of GNSS-enabled Search and Rescue beacons. On the field, GNSS is a valuable tool to coordinate emergency response and humanitarian aid.

Energy and Raw Materials – Monitoring and management of electricity utility grids heavily rely on GNSS timing and synchronisation, allowing the balance supply and demand and ensuring safe operations. In the domain of raw materials, the increased uptake of augmented GNSS supports site selection, planning and monitoring, as well as mining surveillance activities and mining machinery guidance.

Fisheries and Aquaculture – GNSS plays a vital role for the efficient and effective monitoring of fisheries activities through applications such as VMS and AIS. As the focus on the sustainability of these activities grows, agriculture lands diminish and food demand rises, GNSS applications are themselves seeing higher demand.



Forestry – GNSS is becoming an extremely valuable tool in monitoring and maintaining the sustainability of our forests. Besides precision forestry management, a key emerging trend is the use of GNSS-enabled UAVs and tracking devices help ensure the health of our trees and the efficiency of our timber supply chains.

Infrastructure – GNSS contributes to the proper functioning of Infrastructures operations. It allows a safe and on-time completion of construction work through the provision of high accuracy services and supports the synchronisation of telecommunication networks. With the transition towards 5G, the GNSS Timing & Synchronisation function is expected to play an increasingly critical role in telecommunication network operations.

Insurance and Finance – The financial world relies on GNSS timing and synchronisation for the accurate timestamping of financial transactions. Insurers, on the other hand, are turning towards GNSS-enabled UAVs for a more accurate and faster claim assessment.

Maritime and Inland Waterways – GNSS has shown its versatility providing data insights to monitor global shipping and port activities during the pandemic. Looking to the future, with automation and 5G expected to bring technological advancements in ports, GNSS will continue expanding its role beyond merely providing navigation information.

Rail – GNSS is becoming one of the cornerstones for non-safety related applications (e.g. asset management), whilst future adoption of GNSS for safety-related applications, including Enhanced Command & Control Systems, is expected to increase railway network capacity, decrease operational costs and foster new train operations. Thanks to GNSS taking part in digitalisation, Rail is becoming safer, more efficient and more attractive.

Road and Automotive – Despite the global slowdown of car production and sales, regulation for safer and autonomous vehicles is on track, with GNSS doubtless playing a key role. With In Vehicle Systems remaining the dominant source of Positioning, Navigation and Timing, it is moreover clear that public transport is increasingly adopting GNSS to improve its services.

Space – From using real-time GNSS data for absolute and relative spacecraft navigation, to deriving Earth Observation measurements from it, GNSS has also proven its worth for in-space applications. Driven by the NewSpace paradigm, the diversification and proliferation of space users leads to an increasing need for spaceborne GNSS-based solutions.

Urban Development and Cultural Heritage – In this field, GNSS-based solutions are used, in conjunction with EO, to accurately survey and map urban areas and to build advanced 3D models of the built environment. With more than 56% of the population already living in urban areas and this number expected to increase, digital solutions powered by GNSS will be needed more than ever support sustainable growth.

Figure 1 – Role & key trends of GNSS across markets (Credit: EUSPA EO and GNSS Market Report 2022)

2.5 PNT / GNSS Challenges

GNSS signals, which are received with very low power level, are **vulnerable** to radio-frequency interference (RFI) and to natural phenomena (e.g., ionospheric scintillation) which can lead to disruption of GNSS services. Such phenomena can be **deliberate** (**jamming and spoofing** attacks) but can also be **unintentional** (spurious radiation of other radio devices, GNSS multipath propagation).

Although GNSS vulnerabilities are now commonly acknowledged, the **trust** of PNT-based systems or applications goes beyond GNSS and must encompass the **end-to-end-application**, which is only as safe or secure as its weakest component. GNSS is not necessarily the easiest part to attack for maleficent actors: it might be easier or cheaper to hack the output of a receiver to report fake positions than to spoof the incoming GNSS signals. This is for instance how maritime Automatic Identification System (AIS) report positions thousands of km away from the vessel's true position, which is today out of reach of any spoofer.

The International Telecommunications Union issued in July 2022 the Circular Letter CR/488 for the prevention of harmful interference to Radio Navigation Satellite Service Receivers. International Civil Aviation Organization (ICAO) Assembly Resolution A41-8C encourages States to take actions to ensure the resilience of Communication/Navigation/Surveillance and Air Traffic Management (CNS/ATM) systems and services, invites ICAO to obtain more resilient positioning and timing services and encourages standardisation bodies and industry to develop appropriate interference detection, mitigation, and reporting capabilities for the aircraft on-board, satellite- and ground-based CNS system components.

The Radio Equipment Directive 2014/53/EU (RED) establishes the essential requirements that PNT-based devices have to fulfil in order to be placed on the EU market. The RED is the EU legal act that obliges the manufacturers of radio equipment, including GNSS transmitters and receivers, to make an efficient use of the radio spectrum. In other words, RED-compliant products avoid the production of harmful interferences, that constitute the elements that may affect the radio navigation services. The use of harmonised standards in support of the RED developed by the European Standardisation Organisations provides with presumption of conformity to the legal requirements.

Additionally to the measures established in the harmonised standards that reflect the state of the art of the technology, there are today several measures to that may be used to **protect against GNSS jamming and spoofing**:

- **Ensure a clean RF environment** and the use of frequency bands allocated by the International Telecommunication Union is the very first layer of protection for GNSS users.
- **Authenticate the GNSS signals**: GNSS authentication is achieved by incorporating specific features that cannot be predicted or forged by malicious actors in the broadcast signals. A receiver enabled for authentication can interpret these features to distinguish genuine signals from imitations. This can be done at two complementary levels: at the data level, to authenticate the broadcast navigation messages and the range level, to authenticate the measured ranges to the satellites.

- **Use multiple sources of positioning information** to cross-check the solution with independent measurements. This can be done by using multiple constellations and possibly multiple frequencies and/or by complementing GNSS solution with other technologies (as an example, smartphones typically contain many sensors than can be used to provide redundant positioning or movement information).
- **Use a better antenna set up:** adaptive antennas (CRPA) can be a very efficient tool against jamming or simpler configurations (2 antennas) can provide direction of arrival information, which is very useful in detecting incoming spoofing signals.
- **Implement dedicated receiver techniques:** for instance, those based on the monitoring of the signal power or carrier to noise density ratio (C/N0), time of arrival (TOA) discrimination, distribution checks of correlator outputs and consistency checks among different measurements such as ephemeris data, clock offset change or code and carrier Dopplers.
- **Implement Signal Quality Monitoring (SQM) techniques**: originally designed for multipath detection and waveform deformation monitoring, can be used to identify the deformation of the correlation function of typical spoofing attacks. The challenge for spoofing detection and rejection is to discriminate between true signals and unwanted signals. Multipath detection has the same objective and similar techniques are therefore proposed.

  Novel innovative approaches to the correlation process, such as the 'Supercorrelator', claim the capability to separate line of sight and non-line of sight signals during the correlation process, providing multipath mitigation, anti-spoofing, and signal arrival-angle determination. As powerful as they are, such methods are currently implemented only in sophisticated high-grade receivers, but **not widely available in other GNSS chipsets**.

Associated to the low power of GNSS signals, GNSS solutions are mostly unavailable in some environments, such as indoors, underground, or urban canyons. In those environments a mix of technologies (e.g., **hybridisation of GNSS or sensor fusion**) is used to achieve seamless PNT.

Indoor penetration together with high availability, low power consumption and short Time-To-First-Fix (TTFF) are the key requirements for the high-volume market (e.g., consumer solutions, Internet of Things (IoT), automotive solutions, drones, robotics).

Further information can be found in the EUSPA Market Report 2022 and EUSPA Technology Report.

2.6 Trends and Opportunities

The following trends are observed for PNT and GNSS services:

1. **Multi-constellation, multi-frequency is the new norm**

   The four global systems (GPS – US, Galileo – EU, GLONASS – Russia and BeiDou – China), the regional systems (QZSS – Japan and IRNSS – India) and the various SBAS (US, EU, etc.) amount to **100+ satellites**, that thanks to international coordination, have open signals, compatible frequency plans, common multiple access schemes (with GLONASS adding CDMA to its legacy FDMA scheme) and modulation schemes (e.g., Galileo E1 and GPS L1C). This facilitates the design of multi-constellation GNSS chipsets and receivers, to the benefit of end users.

   Furthermore, all global and regional constellations broadcast **open signals in common multiple frequency bands** and SBAS will emulate them with plans to upgrade services to multiple frequencies and multiple constellations in the coming years.

   In addition to the baseline interoperable open signals, each global/regional constellation provides specific services through dedicated signals and frequencies. This is the case of governmental services such as Galileo Public Regulated Service (PRS) or GPS Precise Positioning Service (PPS), as well as value-added services (e.g., Galileo High-Accuracy Service (HAS), QZSS L6 or BeiDou short messaging service).

   Dual-frequency receivers offer significant advantages over single-frequency receivers in terms of achievable accuracy, but also in terms of improved resistance to interference (owing to frequency diversity). Historically, dual-frequency use has been limited for many years to professional or governmental users and to expensive L1 + L2 receivers. The advent of four full GNSS constellations that provide high quality open signals in the E5 frequency band has been a game changer, and has triggered widespread availability of E1 + E5 dual frequency chipsets for the mass market

2. **Receivers, processing methods and antennas are continuously evolving for better performance**

   The evolution of receiver design is enabled by **technological developments** in the **semiconductor industry**, including **increased processing power** to support more GNSS channels, and the development of **low-cost sensors** that allows tighter coupling with different technologies and brings positioning to GNSS-deprived locations. Simultaneously, market pressures exert a pull towards increased accuracy, improved performance in all environments, reduced time-to-first-fix (TTFF) and robustness against jamming or spoofing.

   GNSS errors are usually reduced via two modelling methods: the Observation Space Representation (OSR) provides a single compound ranging correction as observed in a nearby (real or virtual) reference station, while in the State Space Representation (SSR) method, the various error sources are estimated separately by a network of continuously operating reference stations (CORS) before being sent to the receiver. Some parameters (e.g., environmental delays for PPP) are estimated inside the receiver rather than from CORS networks. The PPP-RTK method combines elements from both methods and provides scalable accuracy to all user segments, from mass market to high-accuracy. The **emergence of high-accuracy mass market applications** shows a strong potential for widespread utilisation of PPP-RTK.

   Geolocated IoT devices require the availability of position fixes for very low energy consumption. For this reason, there has been a push to significantly **reduce GNSS energy consumption** over recent years, resulting in rapid advancements in receiver technology (with sub 10 mW consumption in continuous tracking mode at 1 Hz) and the use of several innovative techniques. This includes mature solutions such as assisted GNSS (A-GNSS) or long-term ephemeris predictions, as well as novel hybrid approaches leveraging the connectivity intrinsic to the IoT.

Antennas are a critical part of any receiver design. The best chipsets and most sophisticated signal processing cannot compensate for poor antenna performance. While this importance has long been recognised in high-accuracy segments, other segments including the mass market are only now fully embracing this topic. Indeed, the widespread availability of dual frequency receivers is opening new possibilities, but antennas are a limiting factor for the overall performance.

3. **5G/6G enables ubiquitous connectivity and can contribute to positioning**

   Mobile technology has historically evolved from a people-to-people platform (3G) towards a people-to-information connectivity (4G). **5G** is the first mobile system designed to connect everything. 5G is expected to unleash a Massive Internet of Things (MIoT) ecosystem and critical communications applications, where networks can meet the communication needs of billions of connected devices, with the appropriate trade-off between speed, latency, and cost. **6G**, currently under development, is expected to support applications beyond current mobile use scenarios, such as virtual and augmented reality (VR/AR), ubiquitous instant communications, pervasive intelligence, and the evolution of Internet of Things (IoT).

   Contrary to previous radio networks generations, where positioning was only an add-on feature, **for 5G** mobile radio networks **the positioning is seen as an integral part of the system** and will play a key role, enabling a wide range of location-based services and applications. A key feature technology of 5G positioning is represented by wide band signals in the Frequency Range 2 (FR2), which consists of the operational frequencies that have been allocated to 5G in the mmWave region (above 24 GHz). These wide signals (up to 500 MHz bandwidth) are suitable for better time resolution but also accurate digital beamforming, which in turn enable highly accurate Time of Arrival (ToA) and Direction of Arrival (DoA) estimation especially in direct line-of-sight conditions. Independent 5G infrastructure can also act as an alternative source of PNT, as long as infrastructure does not depend on GNSS.

   It is expected that **complementing EGNSS with 5G** will be the core of future location engines for many applications in the Location Based Service (LBS) and IoT domains, with a significantly improved location performance in cities. With failsafe wireless connections, faster data speeds and extensive data capacity, 5G can provide the connectivity backbone required to enable **cooperative positioning** as well as the safe operation of driverless cars, drones, mobile robots and, more generally, the world of Autonomous Things.

   In the future, **6G** aims to achieve **centimetre-level positioning accuracy** thanks to the use of intelligent reflective surfaces, massive antenna arrays and advanced beamforming and promises to serve applications such as drone delivery, asset tracking, health care monitoring, precision agriculture and autonomous vehicles.

Further detailed information can be found in the EUSPA GNSS User Technology Report.

2.7 PNT systems and services

Historically, **conventional PNT systems**, based on terrestrial / ground-based infrastructure, have played a key role in enhancing and strengthening PNT, services, either in combination with, or independently from GNSS. There are different conventional systems, all making use of different physics principles to serve a special purpose, being the main one to provide an accurate and reliable position and timing solution which enables to navigate from one point in space to another in a safe manner, determining the position and providing derived information such as the speed and the course, to arrive to the desired destination.

Today, modern **PNT systems and services are underpinned by GNSS** thanks to their capacity to maintain world-wide position and time without incomparable performance. The availability of GNSS services is changing at a very fast pace and will continue to do so in the short and medium term. The last years have seen four GNSS (GPS, GLONASS, Galileo and BeiDou) being declared operational to provide global PNT services with multi-frequency capabilities. In addition, ground and space-based augmentation systems improve the performance of the GNSS signals for specific users and typically regionally or locally.

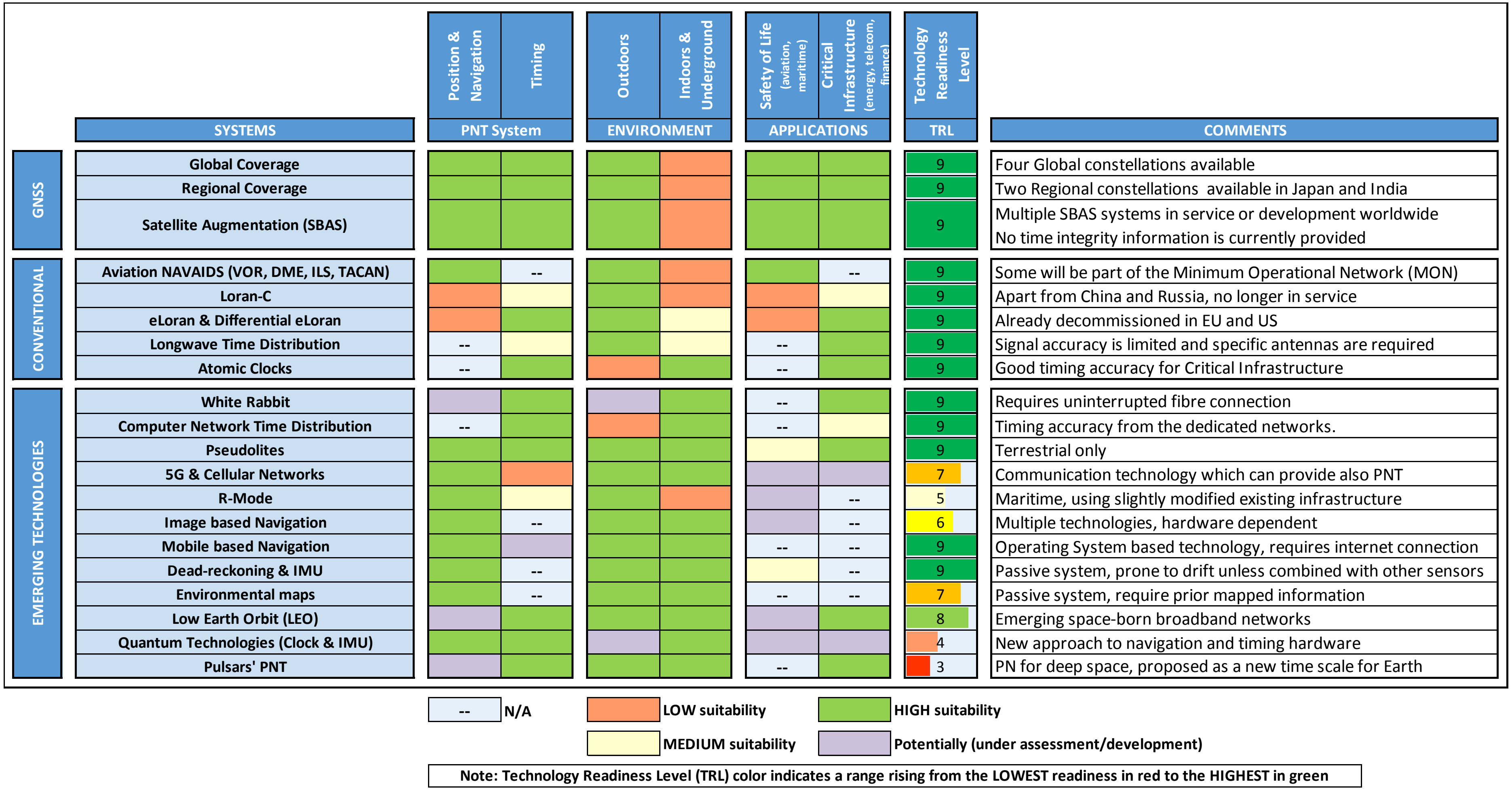
This panoply of interoperable GNSS services will allow **rationalisation** and even **decommissioning** of **conventional terrestrial PNT systems** which will generate maintenance and operational costs savings and electromagnetic spectrum rationalisation. For certain critical applications, like aviation, electricity or banking sectors or civilian emergency services, a backup navigation infrastructure will still be necessary to provide basic guidance capability in case of a GNSS malfunction or outage.

However, and despite is unbeatable success, GNSS services have also certain weaknesses linked mainly to the low power signals which can be easily interfered. This calls for the existence of **Alternative PNT** systems and services able to provide PNT capabilities independently from GNSS (normally with degraded performance). Moreover, Alternative PNT services can also complement GNSS services where GNSS signals are not available (e.g., indoors, underground) thanks to higher signals power. The combination of GNSS and Alternative PNT services enable **resilient PNT services** which are those PNT services that continue operating even upon the loss of GNSS services or in environments where GNSS solutions are not available.

Alternative PNT services can be provided by conventional PNT systems and/or by the so-called **emerging / new generation PNT systems**, which provide PNT services which typically have either lower performance than those of GNSS or with limited coverage or increased cost.

2.7.1 Overview of PNT Systems

All the PNT systems have as their main purpose to provide **accurate and reliable position and timing information** to enable the user device to obtain its location or navigate from one point to another or get synchronised to a time reference. Depending on the technology and nature of the different PNT systems, their suitability to deliver position, navigation or timing information to a specific application may vary. Figure 2 provides an overview on the different PNT systems when classified as **GNSS**, **Conventional** and **Emerging** technologies. The suitability is shown by colours, providing an indication of how each system behaves, depending on several factors such as its performance or deployment feasibility. When a system does not provide a certain functionality, it is indicated with a N/A. This helps in identifying which PNT systems could be more suitable for a particular environment or application, having in mind that other criteria such as for example geographic range, vulnerability to space weather or cost are not considered in this overview. These PNT systems will be described in the following sections with further detailed information provided in **Error! Reference source not found.**.



	SYSTEMS	PNT System		ENVIRONMENT		APPLICATIONS		TRL	COMMENTS
		Position & Navigation	Timing	Outdoors	Indoors & Underground	Safety of Life (aviation, maritime)	Critical Infrastructure (energy, telecom, finance)	Technology Readiness Level	
GNSS	Global Coverage	🟩	🟩	🟩	🟧	🟩	🟩	9	Four Global constellations available
	Regional Coverage	🟩	🟩	🟩	🟧	🟩	🟩	9	Two Regional constellations available in Japan and India
	Satellite Augmentation (SBAS)	🟩	🟩	🟩	🟧	🟩	🟩	9	Multiple SBAS systems in service or development worldwide No time integrity information is currently provided
CONVENTIONAL	Aviation NAVAIDS (VOR, DME, ILS, TACAN)	🟩	--	🟩	🟧	🟩	--	9	Some will be part of the Minimum Operational Network (MON)
	Loran-C	🟧	🟨	🟩	🟧	🟧	🟨	9	Apart from China and Russia, no longer in service
	eLoran & Differential eLoran	🟧	🟩	🟩	🟨	🟧	🟩	9	Already decommissioned in EU and US
	Longwave Time Distribution	--	🟨	🟩	🟨	--	🟩	9	Signal accuracy is limited and specific antennas are required
	Atomic Clocks	--	🟩	🟧	🟩	--	🟩	9	Good timing accuracy for Critical Infrastructure
EMERGING TECHNOLOGIES	White Rabbit	🟪	🟩	🟪	🟩	--	🟩	9	Requires uninterrupted fibre connection
	Computer Network Time Distribution	--	🟩	🟧	🟩	--	🟨	9	Timing accuracy from the dedicated networks.
	Pseudolites	🟩	🟩	🟩	🟩	🟨	🟩	9	Terrestrial only
	5G & Cellular Networks	🟩	🟧	🟩	🟩	🟪	🟪	7	Communication technology which can provide also PNT
	R-Mode	🟩	🟨	🟩	🟧	🟪	--	5	Maritime, using slightly modified existing infrastructure
	Image based Navigation	🟩	--	🟩	🟩	🟪	--	6	Multiple technologies, hardware dependent
	Mobile based Navigation	🟩	🟪	🟩	🟩	--	--	9	Operating System based technology, requires internet connection
	Dead-reckoning & IMU	🟩	--	🟩	🟩	🟨	--	9	Passive system, prone to drift unless combined with other sensors
	Environmental maps	🟩	--	🟩	🟩	--	--	7	Passive system, require prior mapped information
	Low Earth Orbit (LEO)	🟪	🟩	🟩	🟩	🟪	🟩	8	Emerging space-born broadband networks
	Quantum Technologies (Clock & IMU)	🟩	🟩	🟪	🟩	🟪	🟪	4	New approach to navigation and timing hardware
	Pulsars' PNT	🟪	🟩	🟩	🟩	--	🟩	3	PN for deep space, proposed as a new time scale for Earth

-- N/A
🟧 LOW suitability
🟩 HIGH suitability
🟨 MEDIUM suitability
🟪 Potentially (under assessment/development)

Note: Technology Readiness Level (TRL) color indicates a range rising from the LOWEST readiness in red to the HIGHEST in green

Figure 2 – Overview of PNT systems classified as GNSS, Conventional and Emerging

Figure 3 provides an overview of the PNT systems when classified as space and terrestrial systems:

- **Space PNT** systems include constellations of Medium Earth Orbit satellites (MEO) providing GNSS services (section 5.1), Geostationary satellites (GEO) providing GNSS augmentations (section 5.1.3.1) and also the emerging mega constellations of Low Earth Orbit satellites (LEO) (section 5.3.10).
- **Terrestrial PNT** systems include conventional PNT systems such as navigation aids for aviation and maritime or atomic clocks (section 5.2), GNSS augmentation systems such as differential or PPP systems (section 5.1.3.2) and emerging technologies such as 5G, quantum of environmental maps (section 5.3).

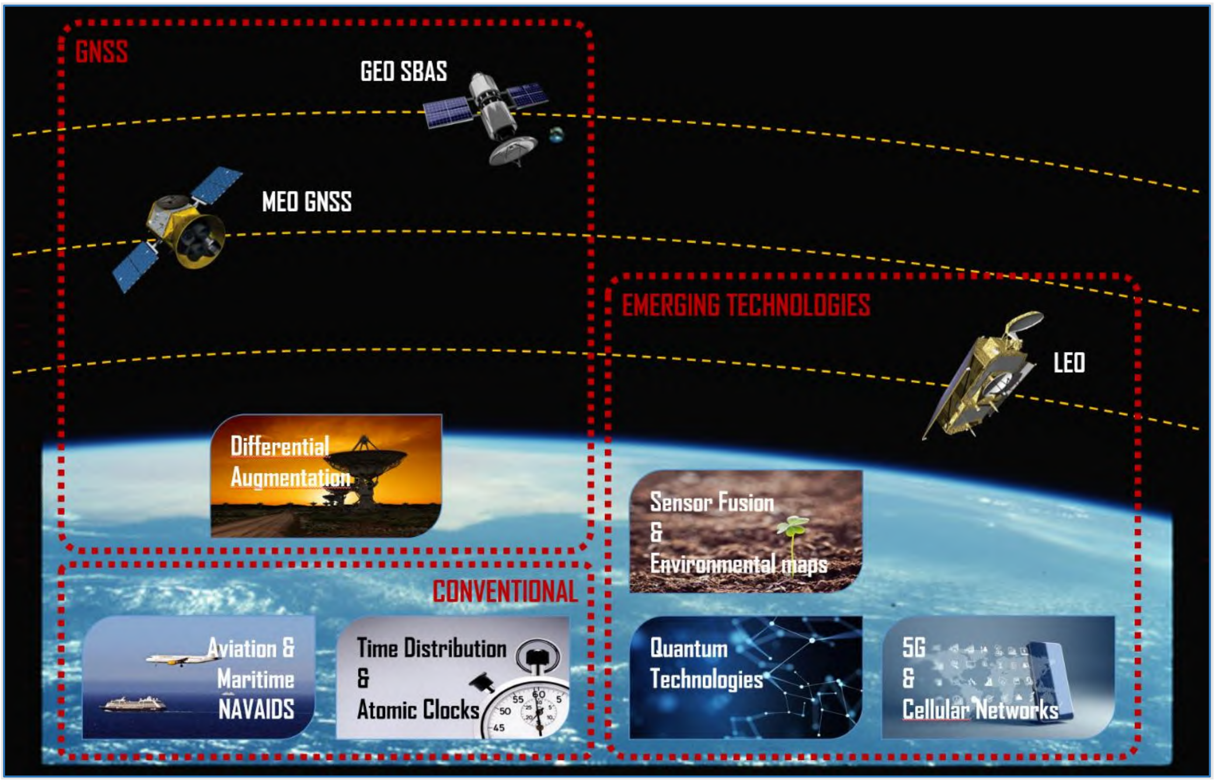


Figure 3 – PNT systems classified as Space and Terrestrial

2.7.2 Global Navigation Satellite Systems (GNSS) & Augmentations

Global Navigation Satellite System (GNSS) is a PNT infrastructure that allows users with a compatible receiver to process signals coming from satellites and determine the position, velocity, and time (PVT). Depending on their coverage, we distinguish between:

- Satellite Navigation Systems – Global coverage**:** Galileo (EU), GPS (USA), BeiDou (China), GLONASS (Russia).
- Satellite Navigation Systems – Regional coverage**:** QZSS (Japan), IRNSS (India).

GNSS performance can be improved by **augmentation systems**, which can be classified as:

- **Space-based**: those where the GNSS corrections are transmitted to users through satellites, and which provide *wide-area* augmentation information (i.e., continental scale).

  One type of these systems is the Satellite Based Augmentation Systems (SBAS) which provide services for aviation and where the following exist today: EGNOS (EU), WAAS (USA), MSAS (Japan), GAGAN (India), KASS (South Korea), ANGA (Central Africa), SouthPAN (Australia and New Zealand), BDSBAS (China) and SDCM (Russia).

  Another type of these systems is Precise Point Positioning (PPP) which enable real-time cm-level positioning accuracy by broadcasting GNSS corrections for a model of the GNSS satellite errors. PPP typically requires tens of minutes to achieve the final position accuracy.

- **Terrestrial-based**: those where the GNSS corrections are transmitted to users through terrestrial means (ground stations or Internet). They typically provide augmentation information to a *local area* (i.e., tens of km) but some also provide wide-area information through Internet (i.e., PPP).

  Some examples of the *local-area* systems are:

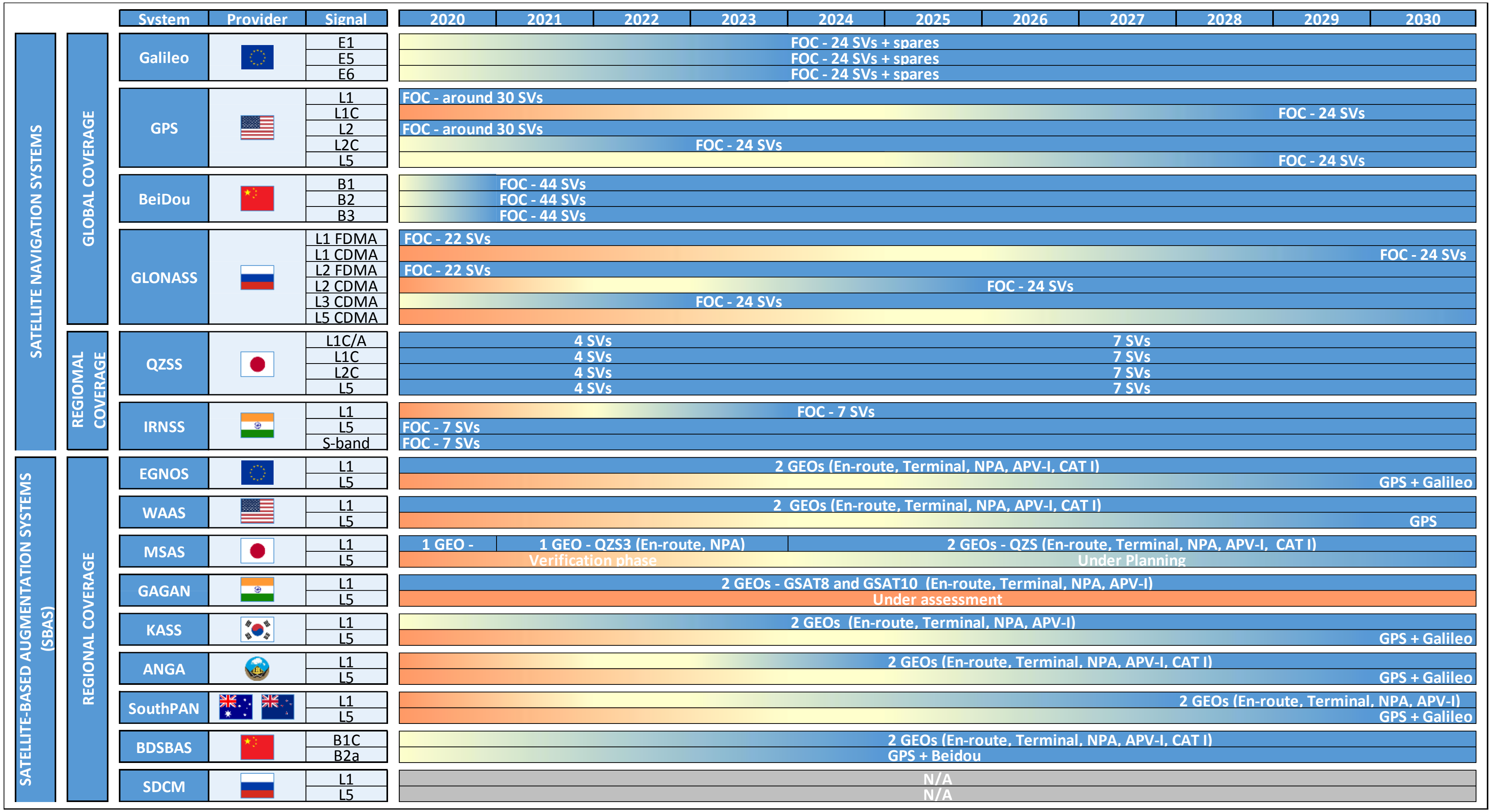
  - Ground Based Augmentation Systems (GBAS) which provide services for aviation with augmentation information including integrity (see section 2.1).
  - Differential GNSS (DGNSS) with augmentation information aimed to improve the accuracy of the user position and which is based on the processing of code GNSS measurements.
  - Real-time kinematic (RTK) which enable real-time cm-level positioning accuracy within few seconds thanks to the processing of phase GNSS measurements.

  Finally, trying to combine the best of the RTK and PPP worlds, PPP-RTK systems have appeared in recent years combining RTK quick initialisation times with the wide-area range of PPP.

- **Receiver-based**: those where the user receiver incorporates augmentation information from navigation sensors. An example of these systems is the Aircraft Based Augmentation Systems (ABAS), where the most widely used is Receiver Autonomous Integrity Monitoring (RAIM).

Detailed information on the various GNSS systems and augmentations is provided in **Error! Reference source not found.** while Galileo and EGNOS services will be discussed in detail in section 3.2 and 3.3 respectively.

The next figures provide an overview of the current GNSS and SBAS systems with some of their main characteristics and timeline.



		System	Provider	Signal	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
SATELLITE NAVIGATION SYSTEMS	GLOBAL COVERAGE	Galileo	🇪🇺	E1					FOC - 24 SVs + spares						
				E5					FOC - 24 SVs + spares						
				E6					FOC - 24 SVs + spares						
		GPS	🇺🇸	L1	FOC - around 30 SVs										
				L1C										FOC - 24 SVs	
				L2	FOC - around 30 SVs										
				L2C				FOC - 24 SVs							
				L5										FOC - 24 SVs	
		BeiDou	🇨🇳	B1		FOC - 44 SVs									
				B2		FOC - 44 SVs									
				B3		FOC - 44 SVs									
		GLONASS	🇷🇺	L1 FDMA	FOC - 22 SVs										
				L1 CDMA											FOC - 24 SVs
				L2 FDMA	FOC - 22 SVs										
				L2 CDMA							FOC - 24 SVs				
				L3 CDMA				FOC - 24 SVs							
				L5 CDMA											
	REGIONAL COVERAGE	QZSS	🇯🇵	L1C/A		4 SVs						7 SVs			
				L1C		4 SVs						7 SVs			
				L2C		4 SVs						7 SVs			
				L5		4 SVs						7 SVs			
		IRNSS	🇮🇳	L1					FOC - 7 SVs						
				L5	FOC - 7 SVs										
				S-band	FOC - 7 SVs										
SATELLITE-BASED AUGMENTATION SYSTEMS (SBAS)	REGIONAL COVERAGE	EGNOS	🇪🇺	L1				2 GEOs (En-route, Terminal, NPA, APV-I, CAT I)							
				L5											GPS + Galileo
		WAAS	🇺🇸	L1				2 GEOs (En-route, Terminal, NPA, APV-I, CAT I)							
				L5											GPS
		MSAS	🇯🇵	L1	1 GEO -	1 GEO - QZS3 (En-route, NPA)				2 GEOs - QZS (En-route, Terminal, NPA, APV-I, CAT I)					
				L5		Verification phase					Under Planning				
		GAGAN	🇮🇳	L1				2 GEOs - GSAT8 and GSAT10 (En-route, Terminal, NPA, APV-I)							
				L5					Under assessment						
		KASS	🇰🇷	L1					2 GEOs (En-route, Terminal, NPA, APV-I)						
				L5											GPS + Galileo
		ANGA		L1						2 GEOs (En-route, Terminal, NPA, APV-I, CAT I)					
				L5											GPS + Galileo
		SouthPAN	🇦🇺 🇳🇿	L1									2 GEOs (En-route, Terminal, NPA, APV-I)		
				L5											GPS + Galileo
		BDSBAS	🇨🇳	B1C						2 GEOs (En-route, Terminal, NPA, APV-I, CAT I)					
				B2a						GPS + Beidou					
		SDCM	🇷🇺	L1						N/A					
				L5						N/A					

🟧 **System NOT in service**

🟨 **System in development/deployment**

🟦 **System in Full Operational Capability (FOC), indicating the number of Operational Satellites (SVs) and Phases of Flight**

Figure 4 – Overview of GNSS Systems

2.7.3 Conventional PNT systems

Conventional PNT systems have been in operation for many years and contain mainly ground infrastructure such as antennas, supporting facilities, monitoring sites and control centres. Conventional PNT systems have the following characteristics:

- **Specific frequency bands and power** which confer the main service characteristics, including the range of the system.
- Typically, **one type of service** is provided such as the provision of bearing, distance, or a combination.
- **Unique and standardised identification at a specific site**, to ease their use with automated systems processing their signals.
- **Design based on well-known and public standards** which define the requirement specification of the system and allows to properly verify and validate the system.

Due to the increased use of GNSS and the obsolescence of some of these conventional systems and the cost to maintain them, there is a tendency for the **rationalisation** while keeping a minimum network which could support operations in the absence of GNSS.

As an **example**, the figure below, extracted from the European ATM Master Plan, shows the expected evolution of the conventional navigation systems (NDB, VOR, DME, ILS) in the **European civil aviation sector**. Several systems are planned to be rationalised or decommissioned in the next decade, a consequence of the successful deployment and ramp up of GNSS and their satellite and ground-based augmentations. The benefit of this infrastructure rationalisation includes operational **cost savings and release of the spectrum bands** occupied by the conventional systems. Nevertheless, to ensure the safe provision of the European air traffic management upon a potential GNSS outage, a **Minimum Operational Network (MON)** of conventional systems will be retained.

It is important to highlight that the evolution plans included in the ATM Master Plan are those envisaged by European Union (also reflecting the evolution plans agreed at ICAO level). However, conventional PNT systems are ultimately the responsibility of the different national authorities which may have specific policies and plans differing from the ATM Master Plan.

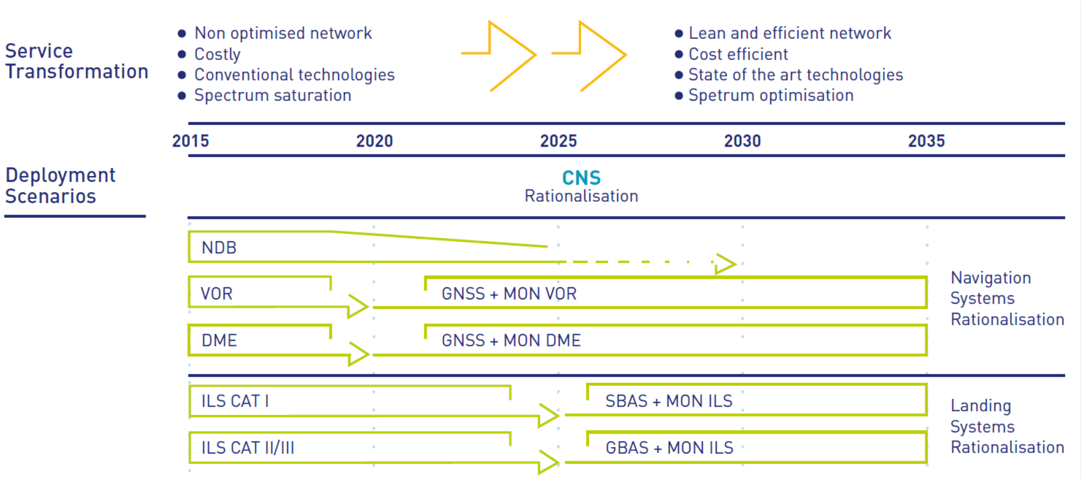


Figure 5 – Rationalisation of Conventional Navigation Aids (Credit: ATM Master Plan)

Finally, Figure 6 provide an overview of the conventional PNT systems with further information provided in Appendix 5.2.

System	Frequency Band	PNT Type		Accuracy	Range	Supported NAV Spec (Aviation)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
		Pos/Nav	Timing														
NDB	From 190 kHz to 1750 kHz	🟩 Bearing with respect to NDB	--	Depends on AFD on-board. ICAO minimum accuracy for NDBs is ± 5°	From 25 NM to 150 NM	--	Decommissioning proposal in the European ATM Master Plan										
VOR	From 108 MHz to 117.975 MHz	🟩 Bearing with respect to VOR	--	Within ± 2°	From 25 NM to 130 NM	RNAV 5	Rationalisation to MON										
DME	From 960 MHz to 1215 MHz	🟩 Distance to the DME	--	Around ± 200 metres (± 0,1 NM)	With VOR: from 25 NM to 130 NM With ILS: around 15 NM	RNAV 5, RNAV 2, RNAV 1, RNP 1 and A-RNP	Rationalisation to MON										
ILS	From 108 MHz to 111.975 MHz	🟩 Hor/Vert Guidance - Precision Apch	--	CAT I: ± 10.5 m (35 ft.) CAT II: ± 4.5 m (25 ft.) CAT III: ± 3 m (15 ft.)	Around 15 NM	--	Rationalisation to MON										
TACAN	From 960 MHz to 1215 MHz	🟩 Bearing and Distance	--	Within ±1° DME portion around ± 926 m (0.5 NM)	Around 200 NM	--	In operation since 1960										
Loran-C	From 90 kHz to 110 kHz	🟧	🟨	< 460 m	Long range Day: up to 600 NM Night: up to 1300 NM	--	Not in use in Europe since 2015										
eLoran and dLoran	From 90 kHz to 110 kHz	🟧	🟩	± 20 m, ± 5m for dLoran	600NM day (Night: up to 1300 NM), dLoran 30 NM (due to Differential Stations)	--	Not in use in Europe since 2015										
DCF77	77.5 kHz	--	🟨	long-term deviation (1 y) between ± 5 ms and ± 150 ms	Around 1000 NM	--	In operation since 1959										
Atomic Clocks	--	--	🟩	Better than nanosecs	No limitation	--	In operation since 1960										

-- N/A
🟧 LOW suitability
🟨 MEDIUM suitability
🟩 HIGH suitability

🟧 System NOT in service
🟩 Minimum Operational Network (MON) according to Reg. 2018/1048 PBN IR
🟦 System IN service (Full Operational Capability - FOC)

Figure 6 – Overview of Conventional PNT Systems

2.7.4 Emerging / Next Generation PNT Systems

In addition to conventional PNT systems or GNSS services, there is a panoply of **emerging or new generation of PNT systems**, which today provide services with typically lower performance than GNSS or with limited coverage or at an increased cost.

Figure 7 provides an overview of the emerging PNT technologies with the highest maturity and perceived importance. The technologies have been grouped mainly based on the perceived hardware similarity and include:

- Terrestrial technologies providing mature timing services with high performance.
- Radio-based technologies, be it ground-based (e.g., pseudolites, R-mode) or space-based (LEO satellites).
- Mobile navigation which is to a certain degree hardware agnostic and depends heavily on sensor fusion, machine learning and backend servers and it is a prominent technology for mass market.
- Non-radio-based technologies such as inertial systems and magnetic sensors.
- Visual, LiDAR or radar-based techniques technologies, which despite not strictly providing PNT are important in sensor fusion.
- Quantum and pulsars, which while not mature yet might offer very interesting performance in the future.

An important characteristic of these systems is their technology maturity (so-called Technology Readiness Levels (TRLs)) indicated in the last column of the above figure. The methodology allocates a number ranging from ‘1’ (basic principles observed - the lowest degree of maturity) to ‘9’ (actual system proven in operational environment – the highest degree of maturity). The higher the TRL, the higher the readiness of the system to be used operationally.

These **emerging technologies** differentiate from the conventional aids and to a certain extend from GNSS, by:

- They are designed as part of the combined offering or sensor fusion approach.
- They do not only provide position but also create an efficient time distribution, though some might need a connection to the UTC.
- They embrace modern hardware and software development practices, leading to rapid development and over-the-air updates. This also means that all units are connected and usually do not need manual intervention after installation.
- They have capabilities for monitoring, reporting and fault identification by themselves.
- They have improved cybersecurity, integration with other systems, user experience and flexibility.

Further information on the systems themselves is provided in the Appendix (section 5.3).

System	Frequency Band	PNT Type		Accuracy	Range	Technology Readiness Level (TRL)
		Pos/Nav	Timing			
White Rabbit (WR)	--	🟪	🟩	Sub-ns / cm	Network, with repeaters up to hundreds of km	9
Computer Network Time Distribution	--	--	🟩	Sub-µsec	Network, with repeaters up to hundreds of km	9
Pseudolites	Various bands (e.g. WiFi, 921.88 – 927.00 MHz)	🟩	🟩	0.2 - 15 ns 0.005 m (carrier) - 15 m (code)	5 - 15 km	9
5G and cellular networks	450 MHz - 6 GHz and 24.25 GHz - 52.6 GHz	🟩 2D	🟩	Tens of meters Sub-µsec	Given by the network infrastructure	7
Ranging mode (R-Mode)	VHF and MF	🟩 2D	🟨	Tens of meters	250 km	5
Image based Navigation	--	🟩	--	Usually on dm level, absolute vary	Based on the system	6
Mobile based Navigation	Bluetooth and WiFi	🟩	🟪	Few meters (height accuracy allows to detect floor)	Bluetooth and WiFi usually tens of meters	9
Dead-reckoning & IMU	--	🟩	--	1m drift after 2min (high grade) 1m drift after few sec (low grade)	No limitations	9
Environmental maps	--	🟩 2D	--	Outdoor: meter to hundres of meters, indoor: < 1m	Depends on the system	7
Low Earth Orbit (LEO)	K and L bands	🟪	🟩	10 ns 10 m static	Global	8
Quantum Technologies (Clock & IMU)	--	🟩	🟩	At least one order of magnitude better than convential IMUs	No limitations	4
Pulsars' PNT	X-Ray (others not so efficient)	🟪	🟩	1000 km	Whole galaxy	3

Note: Technology Readiness Level (TRL) color indicates a range rising from the LOWEST readiness in red to the HIGHEST in green

-- N/A

🟨 MEDIUM suitability

🟩 HIGH suitability (2D indicates 2 Dimensions)

🟪 Potentially (under assessment/development)

Figure 7 – Overview of Emerging / Next generation PNT Systems

2.8 Interoperability and Compatibility

The emergence and modernisation of GNSS (including their regional and augmentation components) entail discussions on **GNSS interoperability** and **compatibility** among the different service providers.

According to the International Committee on Global Navigation Satellite Systems (ICG) '**Interoperability** refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system'.

In the GNSS context, interoperability should be understood as the capability for user equipment to exploit available navigation signals of different GNSS and to produce a combined solution which generally exhibits performance benefits (e.g., better accuracy, higher availability) with respect to the standalone system solution. Interoperability is often discussed at two different levels: **system** and **signal** while interoperability at receiver level is ensured by internationally recognised standards. Further information can be found in Interoperability – Navipedia.

ICG states that '**Compatibility** refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference and/or other harm to an individual system and/or service.'

Two aspects are often considered when assessing compatibility:

- Radiofrequency compatibility (RFC), including factors of cross-correlation properties and affordable receiver noise floor.
- Spectral separation between authorised signals and other signals, and if overlapping is unavoidable, then close discussion among providers is undertaken to guarantee the required service.

Further information can be found in Compatibility – Navipedia.

International cooperation is fundamental to ensure interoperability and compatibility of GNSS signals (e.g., signal structures, messages, carrier frequencies, codes, and modulations) and is conducted from an early stage of development while receiver standards are key to ensure the interoperability and compatibility at receiver level.

Similarly to GNSS, interoperability, compatibility and standards development is necessary for other PNT services (e.g., standards are being developed by IEEE for Resilient PNT user equipment).

2.9 International PNT policies

Recognising the importance of PNT services, national PNT policies exist internationally for the major world economies. An overview of those PNT policies is provided in this section.

The US Federal Radio Navigation Plan (FRP) is the official source of positioning, navigation, and timing (PNT) policy and planning for the US Federal Government. The FRP contains chapters covering Roles and Responsibilities, Policy, representative PNT User Requirements, Operating Plans, and the National PNT Architecture, as well as appendices covering System Parameters and Descriptions, PNT Information Services, and Geodetic Reference Systems and Datums.

In 2018, the US published a National Timing Resilience and Security Act and in 2020 an 'Executive Order on Strengthening National Resilience through Responsible Use of PNT Services' with the purpose to 'foster the responsible use of PNT services by critical infrastructure owners and operators'. Amongst the many actions, the Executive Order called for the implementation of a GNSS-independent source of Coordinated Universal Time. In 2020, the US Department of Transport conducted the testing of 11 selected alternative PNT technologies, with the objective to assess complementary and backup PNT technologies to GPS. The campaign tested both position and time, providing a quantified ranking for the various analysed technologies.

The Russian Radio Navigation Plan, published in 2019 and agreed to by representatives from 11 nations[3] discuss position and timing requirements for different users. The Plan shows a significant concern with disruption of signals from Global Navigation Satellite Systems (GNSS) such as GPS and its Russian equivalent GLONASS and provides for how Russia — and its allies — are making users safer by integrating space and terrestrial systems into a more robust and resilient positioning, navigation, and timing (PNT) architecture. It also confirms a mobile terrestrial PNT capability, likely for military use.

In case of interference, the Plan suggests the creation of a system to monitor GNSS frequencies and identify disruptions, the use of multiple GLONASS frequencies and the integration of GLONASS, GPS and terrestrial systems within users' receiver: 'one of the ways to integrate ground and space Radio Navigation Systems is integration of systems like 'Seagull' [Loran] and GLONASS. Integrated systems 'Seagull'/ GLONASS may in the future used as the main systems for route stages navigation.'

Despite **China** having not published a Radio Navigation Plan yet, their approach has been presented on number of conferences and symposia. China plans to build the world's first comprehensive PNT architecture (e.g., resilient and robust). This architecture is described as a multi-source PNT system that will be 'more ubiquitous, more integrated, more intelligent'. Centred around BeiDou satellites at Medium Earth Orbit (MEO), it will incorporate a wide variety of other PNT sources such as a LEO PNT constellation, Loran-C stations, inertial sensors, and systems like quantum navigation that have yet to be developed.

---

[3] Russian Federation, Republic of Azerbaijan, Republic of Armenia, Republic of Tajikistan, Republic of Belarus, Turkmenistan, Republic of Kazakhstan, Republic of Uzbekistan, Kyrgyz Republic, Ukraine, Republic of Moldova.

In the UK, a Marine Navigation Plan was released in 2016 focusing on the use of PNT services for maritime navigation. In 2017, a report assessed the economic impact to the UK of a five-day disruption to GNSS at GBP 5.2 billion and in 2020, the UK announced the creation of a **National Timing Centre** to ensure additional resilience to GNSS services for accurate timing by means of a network of atomic clocks housed at secure locations.

3 EU PNT

This section discusses the PNT in the European Union covering the objectives 6 to 8 introduced in section 1.4. It aims to provide **detailed information** on the main services provided by the European GNSS systems **Galileo and EGNOS**, to summarise per market segment the **current EU policies** related to PNT and the additional actions that would facilitate EGNSS services and/or increase the resilience of PNT services.

The section will:

- Introduce the EU legal framework for the EU Space Programme (section 3.1).
- Describe the Galileo current services and plans for future services highlighting their added value with respect to other GNSS services (section 3.2).
- Describe the EGNOS current services and plans for future services (section 3.3).
- Describe the EU policies related to PNT, including the on-going activities to facilitate the introduction of EGNSS in EU policies (section 3.4).
- Provide recommendations to facilitate the introduction of EGNSS services (section 3.4).
- Provide recommendations to increase the resilience of PNT services (section 3.4).
- Describe the EU cooperation activities on satellite navigation (section 3.5).

-

3.1 EU Space Programme 2021 – 2027

In April 2021, the Council and European Parliament adopted a Regulation (EU) 2021/696 establishing the new EU Space Programme for the years 2021 to 2027. The regulation calls for the EU Space Programme to ensure:

- high-quality, up-to-date, and secure space-related **data and services**.
- greater **socio-economic benefits** from the use of such data and services, aimed at increased growth and job creation in the EU.
- enhanced EU **security and autonomy**.
- a stronger role for the EU as a **leading actor** in the space sector.

The regulation simplifies the previous EU legal framework and governance system and standardises the security framework. It includes the following EU Space Components:

- **Galileo**: EU's own global navigation satellite system, providing highly accurate global positioning data and supporting emergency response and Search & Rescue.
- **European Geostationary Navigation Overlay Service (EGNOS)**: EU´s regional satellite-based augmentation system (SBAS). It provides safe critical navigation services to aviation, maritime and land-based users throughout the EU.
- **Copernicus**: Europe´s Earth Observation Programme. Through its land, marine, atmosphere, climate change, emergency management, and security services, Copernicus supports a wide range of applications including environmental protection, management of urban areas, regional and local planning, agriculture, forestry, fisheries, health, transport, climate change, sustainable development, civil protection, and tourism.
- **Space and Situational Awareness (SSA):** EU's initiative to monitor and protect space assets from space hazards.
- **Governmental Satellite Communication (GOVSATCOM):** EU's initiative to provide national authorities with access to secure satellite communications.

In addition, the European Commission tabled in February 2022 two new Space flagship initiatives:

- **A proposal for a Regulation on a space-based secure connectivity (IRIS^2)** to ensure worldwide access to secure and cost-effective satellite communications services via a new constellation, for governmental communications and commercial use. It aims to protect critical infrastructures, support surveillance and crisis management, as well as enable high-speed broadband everywhere in Europe to best anticipate future challenges of our economy. This initiative reached at the end of 2022 a political agreement between the European Parliament and Member States.
- **A Joint Communication on an EU approach on Space Traffic Management (STM)** to further strengthen the EU's space surveillance and tracking capabilities (and set clear standards and regulation for a safe, sustainable, and secure use of space.

The EU Space Programme is implemented in close cooperation with the Member States, the European Union Agency for the Space Programme (EUSPA), the European Space Agency (ESA), the

European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and other stakeholders.

Further information on the EU Space Programme can be found in EU Space Programme (europa.eu).

3.2 Galileo Services

Galileo is the **EU's global satellite navigation system**, providing a highly accurate, guaranteed global positioning service under civilian control. While providing autonomous navigation and positioning services, Galileo is interoperable with other GNSS systems such as GPS, GLONASS and BeiDou.

Galileo is made up of a space segment consisting of a constellation Medium Earth Orbit (MEO) satellites broadcasting positioning and timing signals, a ground segment which controls the satellite's operation and generates the navigation information to be transmitted in the Galileo signals and a user segment constituted by the worldwide user terminals. Galileo is **operational since 15 December 2016** and continuously evolving within the Galileo First Generation while the Galileo Second Generation is under development.

The services provided by Galileo shall comprise the:

- **Galileo Open Service (OS)**, which is free of charge for users and shall provide positioning and synchronisation information intended mainly for high-volume satellite navigation applications for use by consumers. It includes the Galileo Open Service Navigation Message Authentication (OSNMA) and Service Volume capabilities.
- **High-Accuracy Service (HAS),** which is free of charge for users and shall provide, through additional data disseminated in a supplementary frequency band, high-accuracy positioning and synchronisation information intended mainly for satellite navigation applications for professional or commercial use.
- **Signal Authentication Service (SAS),** based on the encrypted codes contained in the signals, intended mainly for satellite navigation applications for professional or commercial use.
- **Public Regulated Service (PRS),** which is restricted to government-authorised users for sensitive applications which require a high level of service continuity, including for security and defence, using strong, encrypted signals.
- **Emergency Service (ES),** which is free of charge for users and shall broadcast, through emitting signals, warnings regarding natural disasters or other emergencies in particular areas.
- **Timing Service (TS),** which is free of charge for users and shall provide an accurate and robust reference time, as well as realisation of the coordinated universal time, facilitating the development of timing applications based on Galileo and the use in critical applications.

Galileo shall also contribute to the:

- **Search And Rescue** support service **(SAR)** of the COSPAS-SARSAT system by detecting distress signals transmitted by beacons and relaying messages to them via a return link.
- **Integrity-monitoring services** standardised at the European Union or international level for use by safety-of-life services, based on the signals of Galileo open service and in combination with EGNOS and other satellite navigation systems.
- **Space Weather** information via the GNSS Service Centre and early warning services via the Galileo ground-based infrastructure, intended mainly to reduce the potential risks to users of the services provided by Galileo and other GNSS related to space.

Each of the services will be further described in the next sections.

Further information on Galileo can be found in European GNSS Service Centre | European GNSS Service Centre (gsc-europa.eu).

3.2.1 Galileo Open Service (OS)

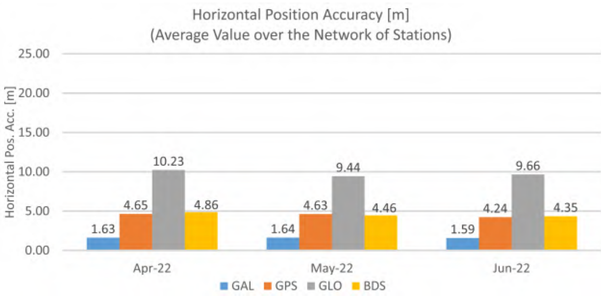
The Galileo Open Service provides **global ranging, positioning, and timing services** for single-frequency and dual-frequency users equipped with a Galileo Open Service compatible receiver. While each Galileo satellite transmits navigation signals (also called Signal-In-Space or SIS) in three frequency bands, the Galileo Open Service is **broadcast on two** out of the three **frequency bands**.

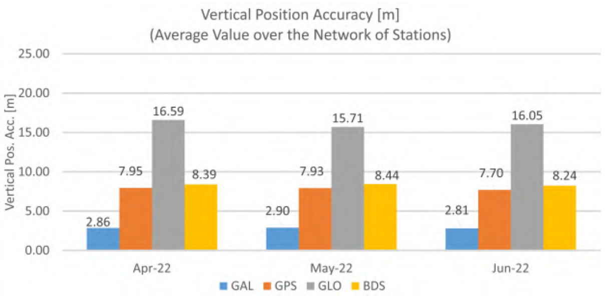
Galileo Open Service Programme Documents include:

- **Galileo Open Service – Service Definition Document**, which describes the characteristics and performance of the Galileo Open Service provided through the Galileo Open Service Signal-In-Space.
- **Galileo Open Service – Signal In Space Interface Control Document**, which contains the publicly available information on the Galileo Signal-In-Space and specifies the interface between the Galileo Space Segment and the Galileo User Segment. It is intended for use by the Galileo user community.
- **Ionospheric Correction Algorithm for Galileo Single Frequency Users**, which describes in detail the reference algorithm to be implemented at user receivers to compute ionospheric corrections based on the broadcast coefficients in the Galileo navigation message for single-frequency users.

Galileo Open Service quarterly performance reports provide detailed information on the performance of the Galileo Open Service with respect to the Minimum Performance Level (MPL) targets specified in the Galileo OS Service Definition Document.

The Galileo Open Service **ranging and positioning accuracy exceed by far those of the other GNSS systems,** achieving a ranging accuracy better than 30 cm (95%) and a horizontal and vertical position accuracy better than 2 m and 2.5 m (in average) respectively. The **timing service accuracy** is better than 5 ns (95%). Galileo Open Service healthy signals are available more than 99% of the time for operational satellites. Typical performance can be found in the Galileo Performance Reports, which show the statistics of the typical GNSS ranging errors.





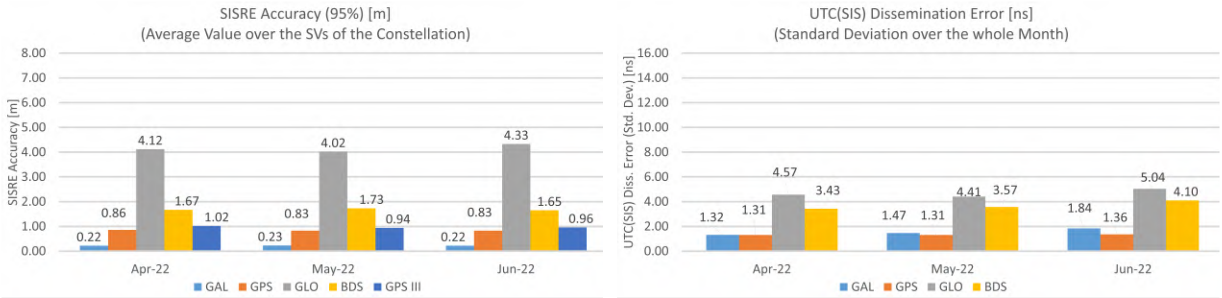


Figure 8 – Galileo Position and Timing Accuracy when compared to other GNSS (GPS, GLONASS and BeiDou)

Further information on Galileo Open Service can be found in its Service Definition Document.

3.2.1.1 Open Service Navigation Message Authentication – OSNMA

As part of a set of innovative services meant to add authentication capabilities, Galileo is introducing a unique feature called Open Service Navigation Message Authentication (OSNMA). This is meant to answer the clear need for **more robust and trustworthy GNSS solutions**. Users may benefit from this enhanced Galileo capability by means of a GNSS receiver or user terminal enabled to process the OSNMA data.

Galileo OSNMA is a **data authentication** function based on cryptographic operations, freely accessible to worldwide users and which provides receivers with the assurance that the received Galileo navigation data is coming from the system itself and has not been modified. OSNMA increases the likelihood of detecting spoofing attacks at data level, hence significantly contributing to the **security of the solution**. The OSNMA data, which are partly unpredictable, can be also exploited by receivers to provide some level of protection against signal replay attacks.

OSNMA provides the means to authenticate several sets of Galileo data through a specific message transmitted within the **I/NAV** Navigation Message broadcast on the **E1-B signal** component.

Table 2 – Galileo OSNMA performance targets

Characteristic	OSNMA
GNSS Receiver Minimal Capabilities	Single frequency E1
Object of Authentication	Nav Data (E1B I/NAV and E5b I/NAV)
Required Components	E1B
Need of Raw GNSS Signal Storage at Receiver Side	need for I/NAV data
Navigation Signals Decryption by GNSS Receiver	No
Authentication	Clock & Ephemeris Data (CED), ionospheric correction, Broadcast Group Delay (BDG), status flags and timing parameters (GPS to Galileo Time Offset – GGTO - and UTC),

Characteristic	OSNMA
	delayed
Time To First Authentication	One to few minutes
Authentication Availability	High, expected above 95%
Other Requirements	Time Synchronisation

OSNMA **public testing phase started in 2021**. It allows receiver manufacturers, application developers or researchers to implement and test the protocol and provide feedback to the Galileo Programme. OSNMA **service declaration** is expected **by the end of 2023**.

The Galileo Second Generation (**G2G**) will **improve the scope and robustness** of the authentication capability of OSNMA and extend it with ranging authentication.

Further information on the Galileo OSNMA can be found in GSC Info Note on OSNMA, OSNMA User ICD and OSNMA Receiver Guidelines.

3.2.1.2 Space Service Volume

Originally designed to offer positioning, navigation, and timing services to terrestrial users, **GNSS** has 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.

With an ever-increasing number of spacecrafts and the continuous development of GNSS spaceborne solutions, Galileo will offer a service for Space users – a **Galileo Space Service Volume (SSV)** as part of the Galileo Second Generation, which will be defined over three regions.

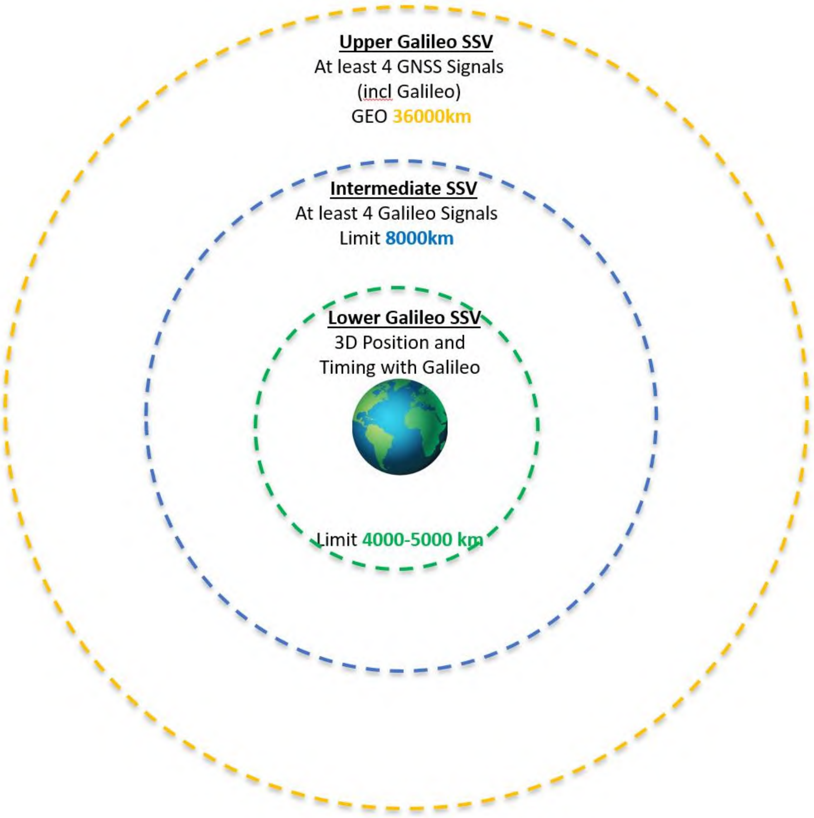


Figure 9 – Galileo Space Service Volume regions

The Galileo **Space Service Volume** will provide **service autonomously up to around 8 000 km altitude** (higher than the 3 000 km defined in the GPS SSV) thanks to the higher orbits of the Galileo satellites while for higher altitudes, a multi-constellation GNSS SSV solution will be required. This will satisfy most of the position and timing performance needs of Space users.

In addition, the international community is working on the **definition of an Interoperable GNSS Space Service Volume**, based on the outcomes of the work carried-out within the Working Group B of the United Nation International Committee on GNSS (UN ICG). As part of the ongoing activities, the Working Group is analysing the convenience of developing Standards in support of GNSS Space Users.

3.2.2 High Accuracy Service (HAS)

Galileo is the first GNSS constellation to provide a **high accuracy positioning service globally** aimed at applications that require higher performance than the one offered by the Galileo Open Service. The Galileo High Accuracy Service is based on the provision of Precise Point Positioning – **PPP – corrections** (orbit, clock, biases, atmospheric corrections) at a maximum rate of 448 bps per Galileo satellite connected to an uplink station, allowing the user to obtain a **horizontal positioning** error better than **20 cm (95%)** in nominal conditions of use.

The Galileo High Accuracy Service comprises two services levels:

- **Service Level 1 (SL1)** with **global coverage** and providing high accuracy corrections (orbits, clocks) and biases (code and phase) for Galileo and GPS signals.
- **Service Level 2 (SL2)** with **regional coverage** and providing **SL1 corrections plus atmospheric corrections** (at least ionospheric) and potential additional biases.

Along with the Galileo High Accuracy Service corrections via the Signal in Space (E6b), it is foreseen that **corrections** will **also** be **distributed using a terrestrial channel**, aiming to provide users (both SL1 and SL2) with an alternative or complementary input source to the Signal in Space.

The Galileo High Accuracy Service will be implemented in two phases:

- **Initial Service** declared on 24 January 2023: provision of Service Level 1 with reduced performance since based on processing of Galileo system data only.
- **Full Service** from 2026: provision of the Service Level 1 and 2 fulfilling target performance.

Table 3 – Galileo High Accuracy Service performance targets

HAS characteristic	Phase 1 (Initial Service)	Phase 2 (Full Service)
Coverage	SL1: EU	SL1: Worldwide SL2: EU
Type of Corrections	PPP – orbit, clock, biases (code and phase)	SL1: as phase 1 SL2: SL1 + atmospheric corrections
Format of Corrections	Open format similar to Compact-SSR (CSSR)	As phase 1
Supported Constellations & Frequencies	Galileo E1/E5a/E5b/E6; E5 AltBOC GPS L1/L5; L2C	As phase 1
Horizontal / Vertical Accuracy 95%	< 20 cm / < 40 cm	As phase 1
Convergence Time	< 300 s	SL1: < 300 s SL2: < 100 s
Availability	> 99%	As phase 1

The Galileo Second Generation (**G2G**) will improve the High Accuracy Service by providing orbit and clock **corrections in other bands** on top of E6 **and** by **enhancing several aspects** such as increased bit rate, faster acquisition additional GNSS constellations and faster convergence time.

Further information on Galileo High Accuracy Service can be found in the Galileo HAS SIS ICD, Galileo HAS Info note and GSC - HAS.

3.2.3 Commercial Authentication Service (CAS) / Signal Authentication Service (SAS)

The Galileo Commercial Authentication Service is based on the **full encryption of the E6C signal** and allows the **user PVT authentication** based on E6C encrypted ranging and OSNMA authenticated Navigation data. The service will be provided in a semi-assisted mode, as **ACAS** (Assisted CAS).

The ACAS concept, which provides user **autonomy between server connections** (for hours/days depending on the user), relies on OSNMA and therefore requires that the receiver is loosely synchronised to the Galileo system time.

The ranging authentication capability relies on retrieving on the server E6C replicas which were re-encrypted with an OSNMA key, then storing snapshots of transmitted E6C signal at predefined instants, and once the OSNMA key is disclosed, decrypt the E6C replicas and perform the correlation with the snapshots, obtaining a-posteriori authenticated range measurements.

The Galileo Commercial Authentication Service will be implemented in two phases with the following objectives:

- **Initial Capability** from 2024 where ACAS services will be based on Galileo capabilities already existing or under development (E6C encryption, OSNMA), plus assistance services integrated in the Galileo service facilities.
- **Full service** from 2026 with the completion of the deployment ground infrastructure.

In addition, an assessment is on-going on the feasibility of a Standalone CAS (**SCAS**), based on market analyses and ACAS adoption. This would require the storage in the receiver of a symmetric secret key and would enable real-time authentication.

For Galileo Second Generation, the performance of these authentication capabilities will be enhanced, and the name will be changed to **Signal Authentication Service** (**SAS**).

Further information on the Galileo Commercial Authentication Service can be found in the European GNSS Service Centre website.

3.2.4 Public Regulated Service (PRS)

The Galileo Public Regulated Service is an **encrypted navigation service** for governmental authorised users and sensitive applications that require high continuity. It is the most secure of the Galileo services and provides **worldwide unlimited and uninterrupted PNT capabilities** to authorised users even in crisis situations.

Access to the service is **limited to the Galileo PRS participants**, which are the Member States, the European Council, the European Commission, and the European External Action Service, as well as European Union agencies, third countries and international organisations, in so far as they have been duly authorised. Third countries and international organisations can become PRS participants subject to the conclusion of international agreements (detailed conditions of access to Galileo PRS are established under Decision 1104/2011/EU).

The **Member States have full sovereignty regarding the national users** authorised to access the Galileo Public Regulated Service and the use cases and application domains.

Only those entities authorised by the Security Accreditation Board can develop and manufacture **Galileo PRS User receivers**. Galileo PRS equipment and technology is subject to export controls.

Galileo Public Regulated Service is providing **Initial Services since December 2016**, including for demonstration purposes, support to PRS user segment technology development and user uptake.

Further information on Galileo Public Regulated Service can be found in GSC PRS and Navipedia PRS.

3.2.5 Emergency Service (ES)

The Galileo Emergency Service, also-called Emergency Warning Service, will include in the Galileo signals **alert messages to population threatened by natural disasters or other emergencies**. The Galileo receivers implemented in various devices (smartphones, smartwatch, handheld, billboards, etc.) will receive and decode these alert messages and display them on screen for immediate information.

This service provides an **additional mechanism** for the civil protection authorities to alert the population and is supporting directly the objectives set in the **United Nations' 'Sendai framework for disaster risk reduction'.**

The Galileo Emergency Service has the following **main characteristics**:

- Global coverage.
- Broadcast via the Galileo E1 frequency band (and later also via the E5 frequency band).
- Resilient to ground destruction since independent from terrestrial communication networks.
- Cover Multi-hazards (e.g., tornadoes, earthquakes, nuclear disaster, terrorist attacks).
- Reach out population in a timely manner (i.e., 2-3 minutes), whatever the size of the area.
- Provision of start time of the emergency, the expected duration and guidance to citizens.
- Only relevant population targeted due to geo-location encoded in the message.
- Interoperable solution studied in cooperation with Japan and India.

The **operational concept** of the Galileo Emergency Service is as follows (see following figures):

- The authorised national emergency centres generate an alert message and send it to the Galileo system via a dedicated secure interface.
- The Galileo system generates an Emergency Warning Message with an ellipse defining target area. The message is uploaded to two Galileo satellites and transmitted down to Earth via the Galileo Navigation Messages. The alert message will be also made available on a server, for further usage and monitoring/archiving purposes.
- The user segment, equipped with a Galileo Emergency Service compatible equipment, receives, decodes, and displays the emergency message. The message is only shown to the users located inside the area of emergency.

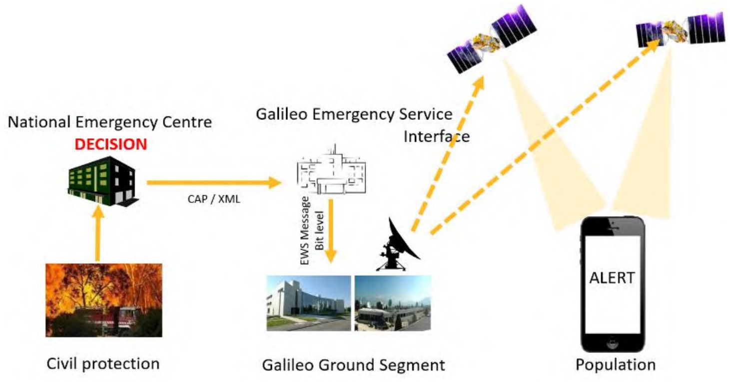


Figure 10 – Operational concept *Figure 11 – Target Area as ellipse*

A **public demonstration phase** is expected in **2023,** while the Galileo Emergency **Service** will be active **from the end of 2024** and evolve in the Galileo Second Generation.

3.2.6 Timing Service (TS)

Despite timing representing a small market, timing services are of **paramount importance for Critical Infrastructure** sectors such telecommunications, energy, and finance. Timing is also exploited in many other domains such as aviation, metrology, remote sensing, and atmosphere research.

The Galileo Timing Service (TS) will provide an **accurate and robust reference time**, as well as a **realisation of the coordinated universal time**, facilitating the development of timing applications based on Galileo and the use in critical applications.

The Galileo Open Service already allows the time stamping of an event with respect to the Galileo System Time and to the Coordinated Universal Time (UTC). In addition, **time sources can be synchronised** to each other (and to an absolute time reference) by using time-distribution techniques.

The Galileo Timing Service will expand the Galileo Open Service current capabilities to better respond to user needs. It will have the following **major characteristics**:

- Synchronisation with higher accuracy levels through the Galileo System Time when compared to other GNSS Systems. The current typical level of timing accuracy is better than 5 ns (95%) and that it will be maintained and even improved through the development of the Galileo second generation.
- Increased robustness and trust in the Galileo Timing Service by being the first GNSS to:
  - Benefit from the authentication of the Galileo navigation messages.
  - Provide dedicated flags for Galileo timing users.
  - Implement a dedicated monitoring with various monitoring levels.

In complement to the Galileo Timing Service, a **European standard for GNSS timing receivers** will be developed. This will be the first ever Timing receiver standard and will become a fundamental piece to ensure the end-to-end user performance of the Galileo Timing Service.

The Galileo Timing Service will be provided in the Galileo Second Generation, as of **2026**.

3.2.7 Contribution to Search And Rescue support service (SAR)

Galileo support to Search and Rescue Service (SAR) represents the **contribution of Europe to the international COSPAS-SARSAT**, a co-operative effort on humanitarian Search and Rescue activities. SAR services detect and locate emergency radio beacons activated by persons, aircraft or vessels in distress and forward this alert to authorities that initiate the rescue activities. Galileo SAR service reduces significantly the time needed to detect a distress beacon after its activation (**< 10 minutes**) and increases the localisation accuracy (uncertainty radius **< 5 km** and < 100 m in the future).

The Galileo SAR service is the biggest contributor to the COSPAS-SARSAT Medium Earth Orbit SAR system (MEOSAR) in terms of ground segment and space segment assets, with **more than 24 SAR transponders** in orbit[4] and **4 MEOLUT ground stations** that relay the distress to the SAR authorities. It is composed of two services:

- In the **Galileo Forward Link service**, the Galileo SAR transponders pick up the signals emitted from distress beacons in the 406 MHz band and broadcast this information to dedicated ground stations (MEOLUTs) in the L-band at 1544.1 MHz. These downlink signals transmitted by the Galileo SAR payloads are used by the MEOLUTs to generate the location of the beacon, which is then relayed to first responders through dedicated COSPAS-SARSAT Mission Control Centres.

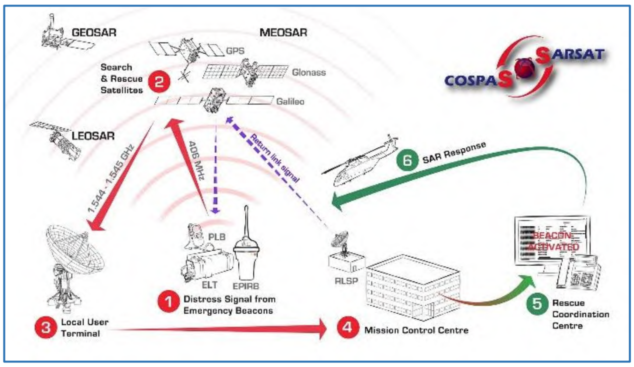


Figure 12 – Operational concept

- The **Galileo Return Link Service (RLS)** allows to send over the Galileo L1 Navigation signal an acknowledge message to the distress user indicating that the alert has been detected and localised. It allows several additional features such as the **Remote Beacon Activation** which will allow authorised users (Aircraft Operators, Maritime Rescue Control Centres) to remotely activate a distress beacon in case, for example, of aircraft disappearance or overdue vessel. This functionality for aviation applications has been standardised in the EUROCAE document ED-277.

In addition, a **Two-Way Communication** via Return Link Service is under assessment. This functionality will allow rescue operators to exchange messages via pre-coded questions and answers and send instructions (how-to-react) to the users in distress equipped with COSPAS-SARSAT beacons. Similarly, a future **Distress Position Sharing** service would allow rescue operators to share through the position of a distress user with other nearby users and enable quicker rescue operations.

---

[4] In 2022, Russia has 2 SAR transponders while US will have its first operational L-Band SART starting on GPSIII block B – current US transponders do not broadcast in the COSPAS-SARSAT allocated frequency band.

The **Galileo SAR Service Definition Document** describes the characteristics and performance of the service while the Galileo SAR quarterly performance reports provide the performance of the Galileo SAR Service with respect to the Minimum Performance Level (MPL) targets specified in the Galileo SAR Service Definition Document.

Further information on can be found in the SAR-SDD, in the GSC SAR website.

3.2.8 Contribution to Safety-of-Life services

Galileo contributes to standardised **integrity monitoring services or safety-of-life services** by providing Open Service signals and information which are combined with augmentation systems:

- Satellite-Based Augmentation Systems (SBAS) such as EGNOS.
- Aircraft Based Augmentation Systems (ABAS) such as Receiver Autonomous Integrity Monitoring (RAIM) and Advanced Receiver Autonomous Integrity Monitoring (ARAIM).
- Ground Based Augmentation System (GBAS).

The use of GNSS signals and its augmentation services is a **fundamental technology in aviation** and has been standardised by the International Civil Aviation Organisation (ICAO). ICAO foresees evolutions of the current Navigation Systems, taking advantage of the Multi-Constellation environment with Dual-Frequency signals (in E1 and E5a bands).

ARAIM is the evolution to multi-constellation and multi-frequency of the current **RAIM**, which is based on GPS and on a single frequency only.

The ARAIM Concept Definition has been developed by the EU/US WG-C and later formalised at international level under the ICAO Navigation System Panel (NSP). While developing the concept, the EU/US WG-C published 3 Reports, being the last one the Milestone III Report.

The introduction of ARAIM will be done incrementally:

- First **Horizontal ARAIM (H-ARAIM)** will support en-route Navigation and will be included in the first version of DFMC MOPS.
- Then **Vertical ARAIM (V-ARAIM)** will support vertical navigation targeting LPV200 operations.

Table 4 – Main characteristics of RAIM vs V-ARAIM

	RAIM	ARAIM
Operations	Down to RNP 0.1	LPV 200
Hazard category	Major	Hazardous
Signals	L1CA	L1CA/E1-L5/E5a
Threat model	Single fault only	Multiple faults
Nominal error model	Gaussian Uses bound broadcast by GPS	Gaussian + nominal/max bias validated by independent ground

	RAIM	ARAIM
		monitoring
Constellations	GPS	Multi-constellation

ARAIM operations will enable vertical approaches down to CAT I / LPV-200 and hence redundancy in areas served by SBAS and will also have a **global coverage** which can support Artic navigation.

Galileo is formally supporting ARAIM thanks to the necessary commitments in the Open Service, reflected in the Galileo Programme documentation (OS SDD, SIS ICD) and in the Aviation Standards (ICAO SARPS) as needed.

3.2.9 Contribution to Space weather information

Space weather events related to solar activity and the interaction with the Earth magnetosphere, can affect both ground and space-based infrastructures, potentially resulting in **disruptions or performance degradation** of satellite services across the globe, sometimes also causing damage to equipment and systems.

GNSS can suffer from electromagnetic phenomena, in particular those happening in the ionosphere. The effects on GNSS navigation can include PNT degradation, temporary position and timing disruption or complete loss of visibility of one or more satellite signals. Considering the increasing reliance on satellite navigation, it is becoming more and more relevant to anticipate the potential degradations and inform/alert users thereof.

Today, **EGNOS** already provides a real-time ionosphere modelling for Europe including Vertical TECs (VTEC) and their bounding while **Galileo** provides a real-time world-wide ionosphere model, much more precise than the Klobuchar model provided in the GPS Navigation Message.

In addition, Galileo will provide an **integrated monitoring and prediction capability** of space weather, allowing to:

- Quantify, predict, and forecast potential impacts of end-user GNSS performance by means of monitoring and forecast:
  - Solar and geomagnetic indices, such as F10.7, R12, Kp, Ap, Dst, as parameters characterising solar events and expected flow of particles towards the Earth.
  - Ionosphere activity parameters, such as Total Electron Content and its derivatives, as well as scintillation events.
  - GNSS performance at user level, such as positioning and timing errors, and loss of lock probability.
- Alert GNSS users in due time of upcoming severe events that may degrade or disrupt GNSS services and so allow a timely reaction to hazard and the activation of mitigation strategies.

This service will process **vast amount of external data** that will in turn feed the monitoring and forecast algorithms. Relevant categories of sensors include geodetic networks (e.g., IGS, EUREF), solar and heliosphere missions, space-based sensors for radio occultation data methods, other ground-based sensors, or network (e.g., ionosondes), and internal Galileo/EGNOS system infrastructure data (e.g., Galileo Sensor Stations).

Several general-purpose space weather monitoring platforms exist around the world, providing bulletins for a variety of space users requiring knowledge of space weather in advance of their operations: human spaceflight, launchers, space surveillance, etc. This Galileo service is deployed as a **Galileo-only platform delivering prediction of performance for its GNSS users**.

The Galileo Programme is currently introducing this capability as a web-based platform into the Galileo Service Centre portal.

Initial declaration of service is planned in **2024**, and regular evolutions are foreseen in the roadmap to cater for the improvement of prediction algorithms or for new methods of collecting data.

3.2.10 Roadmap for Galileo services

Figure 13 provides the overview of the European Commission objectives for the various Galileo services in the period 2023-2025.

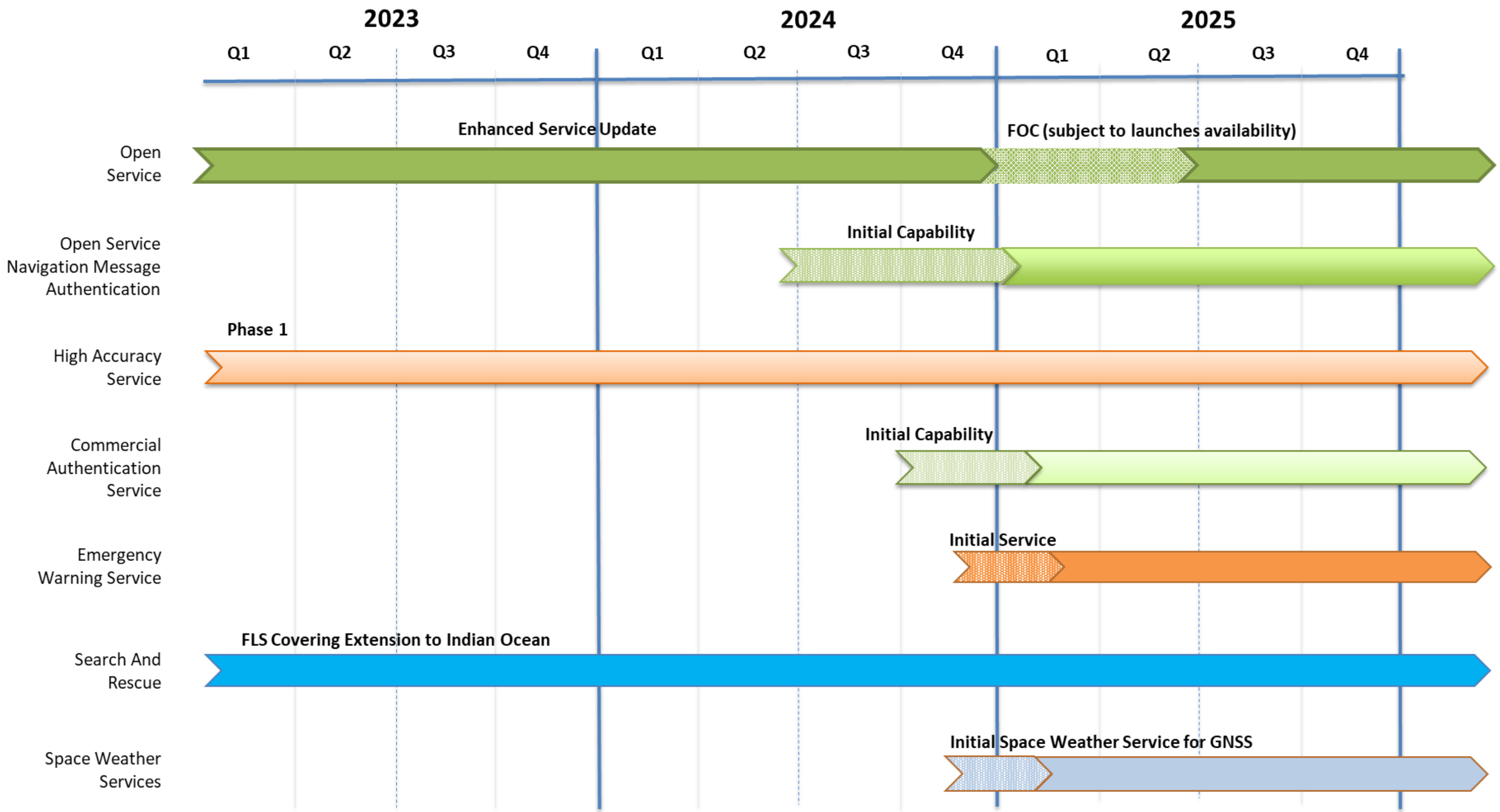


Figure 13 – Galileo services roadmap

3.3 EGNOS Services

EGNOS (European Geostationary Navigation Overlay Service) is the **European Satellite-Based Augmentation Service (SBAS)** that complements the GPS (and Galileo in the future) satellite navigation services.

EGNOS is made up of a space segment (geostationary satellites), ground segment (reference stations, master stations and uplink stations), a user Segment (user receivers processing the SBAS signals) and a support Segment (to support the provision of the SBAS services).

EGNOS reference stations are mainly geographically distributed across Europe and receive GNSS signals which they forward to the master stations. Since the locations of the reference stations are accurately known, the master stations can accurately calculate wide-area corrections. Those corrections are sent to dedicated stations for uplink to the EGNOS satellites which broadcast them to GNSS receivers throughout the SBAS coverage area.

The services provided by EGNOS shall comprise:

- **EGNOS Open Service (OS)**, which shall be free of direct user charges and shall provide positioning and synchronisation information intended mainly for high-volume satellite navigation applications for use by consumers.
- **EGNOS Data Access Service (EDAS),** which shall be free of direct user charges and shall provide positioning and synchronisation information intended mainly for satellite navigation applications for professional or commercial use, offering improved performance and data with greater added value than those obtained through the EGNOS Open Service.
- **Safety-of-Life Service (SoL)**, which shall be free of direct user charges and shall provide positioning and time synchronisation information with a high level of continuity, availability and accuracy, including an integrity message alerting users to any failure in, or out-of-tolerance signals emitted by, Galileo and other GNSSs which EGNOS augments in the coverage area, intended mainly for users for whom safety is essential, in particular in the sector of civil aviation for the purpose of air navigation services, in accordance with ICAO standards, or other transport sectors.

The **EGNOS Service Definition Documents** (SDDs) for OS, EDAS and SoL describe the characteristics and performance of the EGNOS services.

The **EGNOS Monthly Performance Reports** provide detailed information on the performance of the EGNOS OS, EDAS and SoL services with respect to the Minimum Performance Level (MPL) targets specified in their respective Service Definition Documents.

The current EGNOS services (so-called EGNOS V2) provide augmentation to the GPS L1 signal.

The EGNOS Second Generation (so-called EGNOS V3) will provide augmentation to GPS and Galileo L1 and L5 signals. The **technical and operational specifications of EGNOS V3** are established through a Commission Implementing Decision.

Further information on each of the services are provided in the next sections and also in the EGNOS Service Provider website and in their Service Definition Documents.

3.3.1 EGNOS Open Service (OS)

The EGNOS Open Service, available since **1 October 2009,** provides **positioning and timing services** for single-frequency users equipped with a SBAS compatible receiver.

The main objective of the EGNOS OS is to **improve the achievable GNSS positioning accuracy** by *augmenting* the ranging accuracy of the GNSS signals. The accuracy augmentation is possible since EGNOS correct various GNSS ranging error sources: the satellite clocks or orbits and the ionospheric effects. Moreover, EGNOS can also detect distortions affecting the signals transmitted by GNSS and prevent users from tracking unhealthy or misleading signals that could lead to inaccurate positioning.

Typical EGNOS Open Service **performances** for the EU territories include horizontal and vertical accuracies better than 3 m and 4 m (95%) respectively and timing accuracies better than 20 ns (3 sigma) for more than 99% of the time.

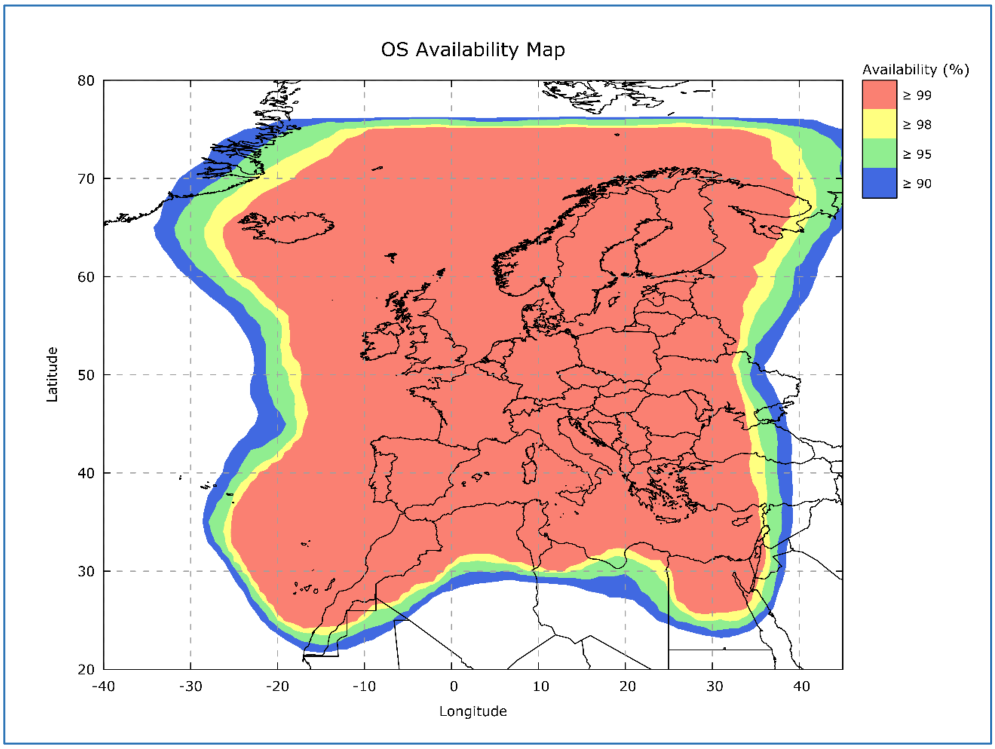


Figure 14 – EGNOS Open Service Availability (source: EGNOS Open Service SDD)

EGNOS Open Service is used for **non-safety critical purposes** (i.e., the absence or incorrect EGNOS Open Service information cannot cause any direct or indirect personal damage, including bodily injuries or death).

The main EGNOS Open Service **users** are precision agriculture, transport applications such as maritime, rail or road and in general any user community interested in obtaining better positioning accuracy.

3.3.2 EGNOS Safety of Life Service (SoL)

The EGNOS Safety-of-life service (SoL) provides the most stringent level of signal-in-space performance to all Safety of Life user communities which require **enhanced and guaranteed performance and integrity warning information**.

It is tailored to **safety-critical transport applications,** and it is provided to the aviation community today and in the future will be provided to the maritime and other communities.

3.3.2.1 EGNOS Aviation SoL

Available since **2 March 2011**, the main objective of the EGNOS SoL service is to support civil aviation operations down to Localiser Performance with Vertical Guidance (LPV) minima (also called approach operations with vertical guidance).

Two **EGNOS SoL Service levels** enable the following SBAS-based operations in compliance with ICAO SARPs Annex 10 Volume I:

- Non-Precision Approach (NPA) operations and other flight operations supporting PBN navigation specifications other than RNP APCH, not only for approaches but also for other phases of flight.
- Approach operations with Vertical Guidance (APV-I) supporting RNP APCH PBN navigation specification down to LPV minima as low as 250 ft.
- Category I precision approach with a Vertical Alert Limit (VAL) equal to 35 m and supporting RNP APCH PBN navigation specification down to LPV minima as low as 200 ft.

The operational use of the EGNOS SoL Service may require specific authorisation by the relevant civil aviation authorities.

The EGNOS SoL Service is accessible to any user equipped **with an EGNOS certified receiver**, in compliance with RTCA SBAS Minimum Operational Performance Standards (MOPS) DO-229[5] and located within the appropriate EGNOS SoL Service area corresponding to the phase of flight in which the EGNOS SoL Service is used (as referred to in EGNOS SoL SDD).

The EGNOS SoL signal also covers territories outside the EU. In this case, authorising and safety oversight of the use of EGNOS in civil aviation is the sole responsibility of the respective third country. The **EU supports the operational use of EGNOS based procedures** in third countries with an equivalent level of safety to the Single European Sky provided there is an agreement between the EU and the third country on the use of EGNOS SoL[6].

---

[5] RTCA MOPS DO 229 (Revisions C, D Change 1 or E)

[6] At the beginning of 2023, there exist EGNOS based operations in the following non-EU states: Norway, Switzerland, Bailiwick of Guernsey, Bailiwick of Jersey, Iceland, Serbia, and Montenegro.

Typical EGNOS SoL **performance** includes the availability of the NPA service better than 99.9% for the European Airspace and better than 99% for APV-I and LPV-200 services (except Azores and partially some parts of Canary, Cyprus, and North of Scandinavia).

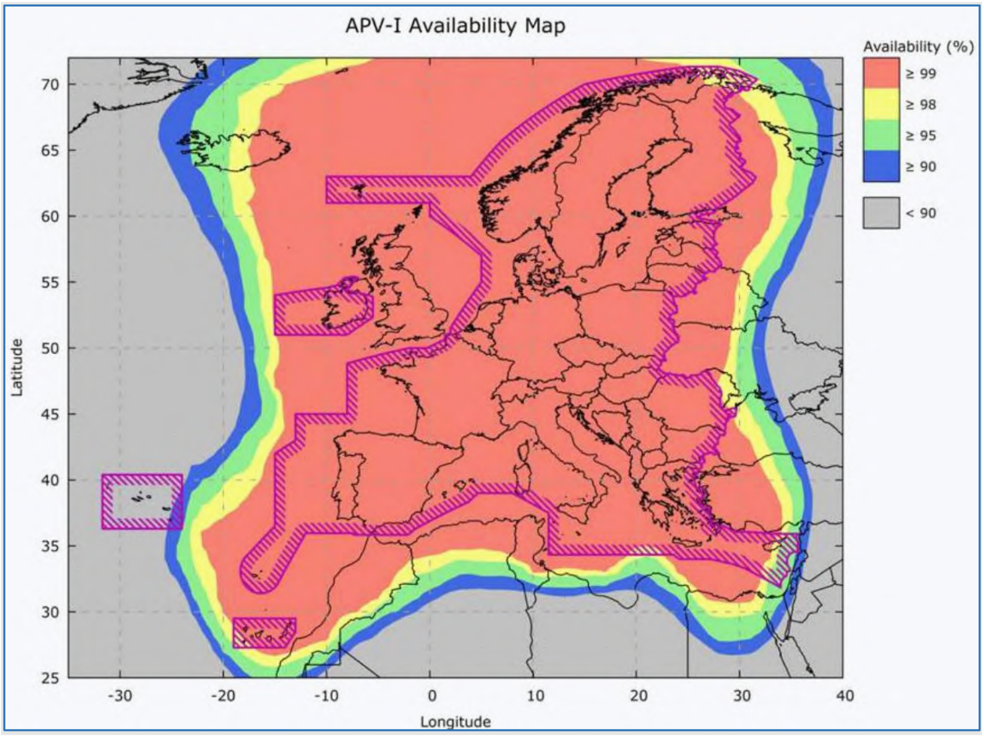


Figure 15 – EGNOS SoL Service Availability (source: EGNOS Safety of Life SDD)

EGNOS V3 (i.e., the next EGNOS generation) will provide improved services according to the following implementation approach:

- **EGNOS v3.1**, in service before 2030, aims to provide **full compliance to ICAO requirements in all the EU territories** when using GPS L1 signals.
- **EGNOS v3.2**, in service around 2030, aims to:
    - Provide DFMC services (dual frequency L1/L5, multi-constellation GPS/Galileo) with increased availability 99.9% for LPV-200 service level and a new service level targeting VAL = 10 m which may enable approval of additional operational capabilities.
    - Extend GPS L1 Legacy services to the European Neighbourhood Policy South[7] and East[8] Territories.

In addition, **authentication of the SBAS messages** is currently under inclusion in the DFMC SBAS Standard and will then add resilience to the DFMC SBAS services.

---

[7] Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine, Tunisia.

[8] Armenia, Azerbaijan, Belarus, Georgia, Moldova, and Ukraine.

3.3.2.2 EGNOS Maritime SoL

The provision of EGNOS services for the maritime users is implemented in three phases:

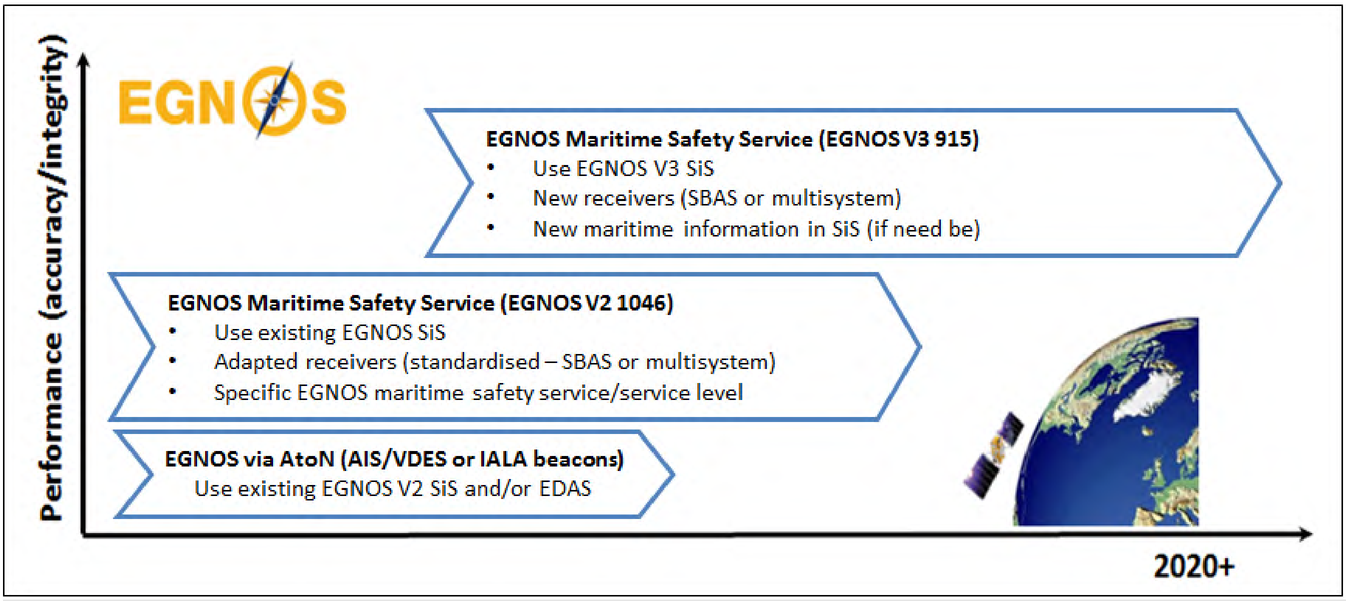


Figure 16 – Phases of implementation of EGNOS Maritime SoL

- **Phase 1: EGNOS corrections transmitted via existing Aids to Navigation (AtoN)**

  The current EGNOS SoL L1 service is used as a source for the differential corrections transmitted via the existing IALA beacons and AIS stations (AtoN) according to the IALA Guidelines G1129 on the retransmission of SBAS corrections using MF radiobeacon and AIS.

- **Phase 2: EGNOS L1 maritime service + dedicated L1 receivers**

  The current EGNOS SoL L1 service will be tailored for maritime users by providing the following **additional information:**

  1. Signal in Space commitments on range (orbits + clock) and ionospheric errors
  2. Integrity Alerts (system alerts, satellite alerts, ionosphere alerts)
  3. Maritime Safety Information to inform about planned/unplanned outages

  In addition, an **IEC test standard for SBAS in shipborne receiver** (IEC 61108-7) is under development which will allow obtaining of the receiver type certificate for the processing of this EGNOS maritime L1 service.

  This Service will be used by shipborne receivers to compute a navigation solution in line with the operational requirements included in the **IMO Resolution A.1046** for maritime navigation in ocean waters, harbour entrances, harbour approaches and coastal waters.

Table 5 – IMO Resolution A.1046 Operational requirements

	Ocean Waters	Harbour entrance, harbour approach and coastal waters
Accuracy (95%)	100 m	10 m
System integrity (Time to Alarm)	As soon as practicable by Maritime Safety Information	Within 10 s
Signal availability	99.8%	99.8%
Continuity	N/A	99.97% (over 15 minutes)

The declaration of this EGNOS maritime service is targeted by the **end of 2023**.

- **Phase 3: EGNOS DFMC maritime service + dedicated new multi-system shipborne radionavigation receivers (MSR)**

  The future EGNOS DFMC service will allow for **improved navigation** as per IMO Resolution A.915(22) and A.1046(27) in harbour entrances, harbour approaches and coastal waters when processed by tailored multi-system shipborne radionavigation receivers.

3.3.2.3 EGNOS Railway Service for train localisation

The introduction of EGNOS Services covering railway **safety-related applications** is **expected to increase safety, increase** railway network capacity, whilst decreasing operational costs.

The inclusion of EGNOS in European Rail Traffic Management System (ERTMS) and the definition of this EGNSS rail service for train localisation is currently under study.

3.3.3 EGNOS Data Access Service (EDAS)

EDAS is the **single point of ground-based access for EGNOS data,** including that generated by the EGNOS ground infrastructure, mainly Ranging and Integrity Monitoring Stations (RIMS) and Navigation Land Earth Stations (NLES).

EDAS services are **accessible through the Internet** regardless of whether the EGNOS GEO is in view. This is especially important in urban canyons, mountain terrains or other areas with limited visibility of the GEO satellites.

EDAS is **accessible to registered users** within the EGNOS Participating countries (Member States, Norway, Switzerland, and Iceland) and to other users upon registration and authorisation by the European Commission.

In addition, existing Maritime, and Inland Waterways transmission infrastructure (IALA beacons and/or AIS base stations) can rely on the **retransmission of DGPS corrections based on EDAS**.

EDAS is available free of charge since **26 July 2012** and can only be used for non-safety critical purposes.

3.4 EU PNT policies and recommended actions

This section will focus on the EU's main policies and actions related to PNT and will include:

1. A **summary**, per market segment, **of the major EU initiatives relevant to PNT**, with a highlight on the role of the European GNSS services.
2. **Recommendations**, including for regulation or standardisation to:
    - Facilitate the use of Galileo and EGNOS in the relevant market segments.
    - Increase the resilience of PNT services, notably for Critical Infrastructure.

This section also addresses the recommendation 4-c of the **Special Report 07/2021** of the European Court of Auditors. The time schedules for each relevant market segment, where regulation or standardisation can facilitate the use of Galileo are detailed in **Error! Reference source not found.**. Future versions of the ERNP will reflect the evolution in the use of Galileo in different market segments.

Before discussing the EU PNT policies per market segment, Figure 17 illustrates how PNT systems are typically used for the various market segments:

- Starting from the **inner circle**, the services from the **global and regional GNSS** systems are being extensively used today in all market segments and can be considered as the backbone for all PNT services. The reason behind is the relatively low cost, outstanding performance, and ease of use of GNSS receivers.
- The second circle shows the services from the **augmentation GNSS** systems which also serve all market segments and provide improved performance for added-value services (e.g., integrity for safety-of-life applications or high-accuracy in PPP).
- The outer circle shows how **conventional PNT** systems are used mainly in the aviation and maritime domains, while **emerging technologies** have the potential to serve all market segments including those environments where the use of GNSS services is more challenging (e.g., indoors).

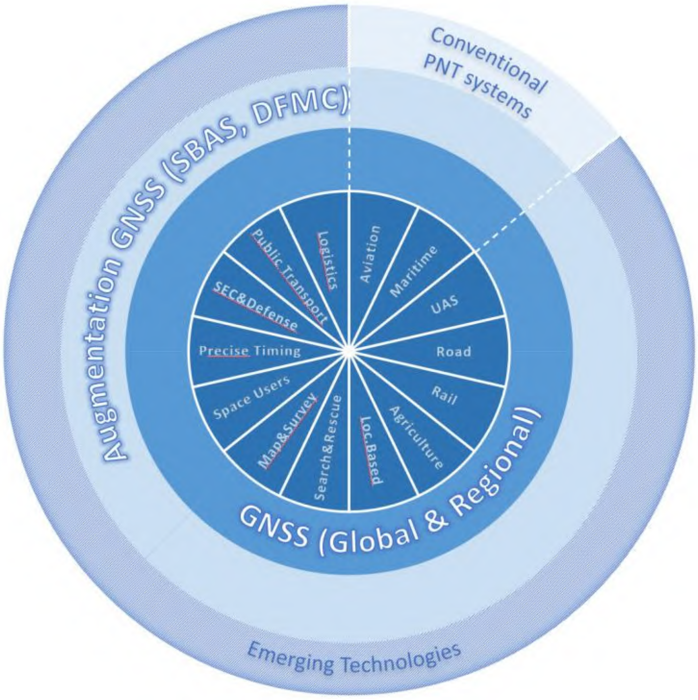


Figure 17 – Overview of technologies per domain

3.4.1 Resilience of European Critical Infrastructures

Ensuring the **resilience of entities that use critical infrastructure to deliver essential services** remains high on the agenda of the European Union and its Member States. The EU Security Union Strategy for 2020-2025 and the Counter-Terrorism Agenda for the EU, both stressed the importance of ensuring the resilience of critical infrastructure in the face of physical and digital risks. The Covid-19 pandemic demonstrated major complex threats to the services on which the lives of European citizens and the good functioning of the internal market depend. Critical infrastructures resilience is highlighted in key political declarations, such as the EU leaders' Versailles declaration.

The European Commission supports Member States to ensure resilience on various levels:

- The Critical Entities Resilience Directive (EU) 2022/2557 (CER Directive) which establishes obligations to identify critical entities in different sectors, in order to enhance their resilience, ensuring that services which are essential for the maintenance of vital societal functions or economic activities are provided in an unobstructed manner in the internal market.

  The Directive will strengthen the resilience to a range of threats **ensuring that critical entities can prevent, resist, absorb and recover from disruptive incidents**, no matter if they are caused by natural hazards, terrorist attacks, insider threats, or sabotage, as well as public health emergencies like the recent COVID-19 pandemic. The Directive reflects the increasingly complex operational reality, the shift of perspective from 'protection' to 'resilience' in academia, industry, and policy making. The CER Directive does not cover cyber security risks.

  Against an ever more complex risk landscape, the Directive has a wider sectoral scope which will allow Member States and critical entities to better address interdependencies and potential cascading effects of an incident. **Eleven sectors are covered**: energy, transport, banking, financial market infrastructures, health, drinking water, wastewater, digital infrastructure, public administration, space and production, processing, and distribution of food.

PNT services and their resilience are relevant for many of the sectors covered by the Directive, notably for transport, energy, telecommunications, and finance and hence should be assessed as part of the **risk assessments** to be carried out by critical entities and **resilience-enhancing measures** implemented when required. Since the CER Directive will also cover the ground segments of space infrastructure operated by Member States or private operators, it will also increase the resilience of the entities that provide PNT to other sectors of the economy.

Finally, the Directive lays the ground for **closer cooperation at EU-level** and serves as reference point also for legislative and regulatory activities on critical infrastructure outside of the EU.

- The Directive (EU) 2022/2555 (NIS 2 Directive) which establishes measures for a high common level of cybersecurity across the EU for the same entities identified under the CER directive. It will boost the overall level of cybersecurity in the EU by promoting a culture of security across sectors and ensuring the Member States' preparedness and cooperation (e.g., requiring a Computer Security Incident Response Team (CSIRT) and creating a Cooperation Group to support and facilitate strategic cooperation and the exchange of information among Member States).
- In October 2022, the European Commission adopted a proposal for a Council Recommendation to strengthen the resilience of EU critical infrastructure. The priority is given to the key sectors of energy, digital infrastructure, transport, and space.
- The Commission Delegated Regulation (EU) 2022/30, which imposes requirements on cybersecurity, privacy and protection from fraud to certain categories of radio equipment, including those used under critical infrastructure, as a condition for its placing on the EU market. The evolution of this legal act will constitute the Cyber Resilience Act.

3.4.2 European Green Deal

Europe has set out to address the **global challenge of climate change and environmental degradation** and will play an instrumental role in reversing the damages protecting, preserving and restoring biodiversity and ecosystems, mitigating the impact of climate change that human practices have induced whilst supporting the planet’s recovery. Europe’s commitment has been made evident through several agreements, initiatives, policies, and regulations over the years. The game-changing sustainable growth strategy known as the European Green Deal (EGD) and its initiatives aim to achieve climate neutrality by 2050 in a just and inclusive manner, encouraging a low-carbon and climate resilient economy. The Green Deal helps advancing towards a well-being economy that gives back to the planet more than it takes and accelerates the transition to a non-toxic circular economy, where growth is regenerative, resources are used efficiently and sustainably.

The European Greed Deal calls for capacities, tools, and services to monitor anthropogenic carbon emissions but also to monitor, analyse, predict, and mitigate the impacts of human activities on soil, air, water quality. The utilisation of **Earth Observation and meteorological data**, together with in-situ data (e.g., ground sensors, etc.) and other non-satellite-based data (e.g., mobile data, statistics, etc.), offers a unique capability to monitor on a global, and yet precise enough scale, the state, and changes of the environment, informing policies and further mitigation and adaptation actions.

GNSS radio occultation provides in situ water vapour profiles and is used to **enhance meteorological forecasts** and GNSS observations allow to estimate geodetic properties of the Earth (magnetic field, atmosphere) that **supports climate modelling.** GNSS also provide precise orbit determination of environmental LEO satellites which monitor the Earth climate change.

The EU Space Programme is a pillar in the space-based transformations towards a healthier planet also thanks to the **advanced PNT data** provided by Galileo and EGNOS. It generates environmental benefits with a positive effect on Europe's Green Deal objectives and activities, for example:

- In the **aviation and maritime sector** GNSS enables efficient travel routing leading to the **reduction** of a fuel use and the associated **Green House Gas emissions**, for example thanks to the less time spent for incoming planes when circling airports waiting for a runway.

  In addition, accurate monitoring of the aircraft position, as well as of weather conditions and occurrence of ice-supersaturated areas would reduce the generation of **persistent contrails and the associated non-CO_2 effects**.
- In the **agriculture sector** GNSS enables automatic steering of agriculture machines and brings reduced soil compaction improving soil health and its capacity to store carbon.
- In the **rail sector** GNSS-enabled driver advisory systems optimise train driving and reduce the consumption of traction energy and thus Green House Gas emissions.
- In the **road sector** GNSS enables shorter and more efficient journeys which result in lowering the amount of time a vehicle engine is engaged and consequently lowers the carbon impact of each journey.
- In the **power distribution sector** GNSS enables accurate timing and synchronisation of the power transmission infrastructure. This is fundamental for the proliferation of smart grids and for the maintenance of accurate voltage frequency, needed due to the increased use of renewable energy for the green transition.
- In the **monitoring offshore infrastructure** (e.g., wind turbines or oil platforms) GNSS enables more efficient drones' operation than the traditional means which dramatically reduces Green House Gas emissions.

3.4.3 Manned Aviation

PNT (notably GNSS and its augmentations SBAS, ABAS and GBAS) **play a key role in aviation** for Communications, Navigation and Surveillance (CNS) systems and applications which support Air Traffic Management (ATM) and increase airport capacity and environmental and economic efficiency (e.g., lower noise impact, more efficient route, fuel and emissions savings) while guaranteeing safety:

- **In Communications,** a **trustful time reference**, as the one based on GNSS, is key for applications such as the synchronisation of ground networks and the CPDLC (Controller Pilot Data Link Communications) enabling ATC communications via data link.
- In **Surveillance**, the full surveillance system, from the sensors to ATC, makes use of a **single time reference**, ensuring that ATC decisions are taken based on reliable surveillance information (as a drawback, GNSS becomes a single mode of failure, rising the need for alternative Timing services). The benefits of the GNSS performance are recognised through ADS-B integrating GNSS information. For example, the US mandate on ADS-B de facto requires the use of SBAS to guarantee the feasibility of operations. Finally, ADS-B based on GNSS positioning may allow the rationalisation of SSR infrastructure.
- In **Navigation**, GNSS is essential to implement Performance Based Navigation (PBN). Among the navigation operations, RNP Approaches down to LPV (Localiser Performance with Vertical guidance) minima are the most essential function provided by SBAS technology, the so called **LPV approaches** (i.e., 3D approaches which provide lateral and vertical guidance similarly to ILS CAT I approaches but with no on-site radio-navigation ground infrastructure). If the minima of the approach operation is below the cloud ceiling, the operation is feasible, **minimising the disruptions** (i.e., cancellations, delays, or diversions to other airports) **and improving safety, efficiency, and accessibility**. Minima down to 250 ft and 200 ft can be obtained at non-precision and precision approach runways respectively, and in both cases it is possible to fly the final approach segment down to 100 ft or even touchdown without visual contact with the runway environment when **combining the use of SBAS with aircraft equipped with EFVS** (Enhanced Flight Vision System) provided that the EFVS on board has the proper characteristics and that there is a Special Approval by the National Competent Authority.

It is worth mentioning that GNSS does not only add value on the ground systems, but it is extensively used also by **on board systems** and applications in the aircraft, in particular for timing purposes.

In addition, **other benefits of using GNSS** are further described in the Aviation User Needs and Requirements report such as SBAS based approaches at Non-Instrument runways for General Aviation environments (normally VFR small aerodromes), rotorcraft operations often in non-optimal conditions for Search and Rescue (SAR) or Helicopter Emergency Medical Services (HEMS) operations and the use of geometric altitude based on SBAS for the development of improved ground warning systems such as Enhanced Ground Proximity Warning System (EGPWS) over the classical Terrain Avoidance and Warning System (TAWS) and the monitoring of baro-altitudes.

In the future, the inclusion of **Galileo and EGNOS DFMC will bring additional benefits** to aviation such as improved performance (e.g., improved availability and continuity), larger SBAS service areas, lower protection levels meaning more advanced operations, capability to support CAT III operations based on GBAS in all latitudes, increased robustness against RFI or mitigation to ionosphere vulnerabilities or support to future applications such as 4D Navigation through GNSS Timing.

To facilitate the use of GNSS for the European air traffic management, some major initiatives exist. The **European ATM Master Plan defines the roadmap for the use of EGNOS and Galileo, in combination with GPS, for different phases of flight** (as part of the CNS systems). Its CNS roadmap includes milestones for the operational use of systems augmenting GPS and Galileo: EGNOS V3 (DFMC SBAS), Advanced RAIM and GBAS.

The Commission Implementing Regulation (EU) 2018/1048 (the 'PBN IR' Regulation) mandates the gradual implementation of **Performance Based Navigation** (PBN) routes and approach procedures to enhance airspace design hence supporting safer, greener, and more efficient aircraft operations and at the same time improving cost efficiency. It requires from 2030 that all SID & STAR are based only on PBN, with GNSS as the main mean of navigation, and makes SBAS the main means of navigation for CAT I operations. In addition, it requires the **implementation of PBN approach procedures including EGNOS procedures** (LPV procedures) in all European IREs (Instrumental Runway Ends) by 2020 (IREs without precision approach) and 2024 (IREs with precision approach).

In addition and with the goal to enable the **rationalisation of the conventional navigation infrastructure** and also ensuring a minimum level of service with an acceptable level of safety in case of contingency (e.g., GNSS outage), the PBN IR expressly excludes the use of conventional navigation procedures as from 6 June of 2030, except in the event of PBN contingencies, i.e., situations where, for unexpected reasons beyond the control of ATM/ANS service providers, GNSS or other methods used for performance-based navigation are no longer available. For these exceptional cases, the PBN Regulation requests to retain a Minimum Operational Network (MON) of conventional navigation aids (e.g., ILS, VOR, DME) to ensure that navigation services can still be provided without compromising safety and security in case of contingency.

Therefore, from 6 June 2030, GNSS will be the nominal means of navigation in the European airspace for all phases of flight down to and including CAT I, complemented by GBAS and ILS CAT II/III landing systems, where necessary (Transition to PBN Operations).

In addition to the regulatory actions like the PBN Regulation, the European Union is facilitating the adoption of PNT and European GNSS in aviation policies by:

- **Supporting, including funding, the implementation and compliance to the PBN Regulation** through different actions oriented to ease both the equipage of the European fleet with GNSS enabled receivers and the implementation by the Air Navigation Service Providers of GNSS based procedures.
- **Broadening the scope of EGNSS usage** for rotorcraft operations, SBAS-based approaches at non-instrument runways, and developing tools supporting the implementation of EGNOS.
- **Funding programmes** supporting R&D on GNSS applications such as the SESAR project.
- Working on the inclusion of **Galileo and EGNOS Dual Frequency Multi-Constellation (DFMC) in aviation** signal-in-space **standards** ICAO Annex 10 Volume I and EUROCAE receiver standards (for SBAS, A-RAIM and GBAS augmentations).

Moreover, there are ongoing activities in Europe (e.g., SESAR, EUROCAE, EUROCONTROL) to define **Complementary PNT technologies** which **could provide secure and resilient PNT**, offering an **effective backup in the event of GNSS** disruption and therefore ensuring continued operations. In the short term, this focuses on improving DME infrastructure and service provision, which will likely support RNP 1). In the long term, a suitable mix of complementary PNT should provide assured PNT, safeguarding against both safety and security PNT threats, while optimising the radio spectrum use of these systems, in line with ICAO Assembly Resolution A41-8C.

3.4.4 Unmanned Aviation

The Unmanned Aircraft System (UAS or drones) market has been quickly increasing in the recent years. **ICAO** has established the Remotely Piloted Aircraft Systems Panel (RPASP) to develop the required **standards for international flights** and the Unmanned Aircraft Systems Advisory Group (UAS-AG) to advise the ICAO Secretariat in developing guidance material. ICAO is also setting up an Advanced Air Mobility Study Group to provide similar guidance to support the development of advanced and urban air mobility. PNT will be a key enabler for many of the UAS applications similarly to manned aviation (e.g., PNT support to CNS applications).

In Europe, Regulation (EU) 2018/1139 (the *EASA Basic Regulation*) extended the scope of competences of EASA to all unmanned aircraft, irrespective of their weight and size, and introduced a risk-based, operations-centric approach to the safety regulation of aviation, in particular for drones. Subsequent Regulations (EU) 2019/947 and 2019/945 set out **the framework for the safe operation of civil drones in the European skies**, distinguishing three categories for the UAS operations depending on the associated operational risk: '**Open**' category (for low-risk operations), '**Specific**' category (for medium-risk operations) and '**Certified**' category (for higher risk operations including the transport of people or dangerous goods).

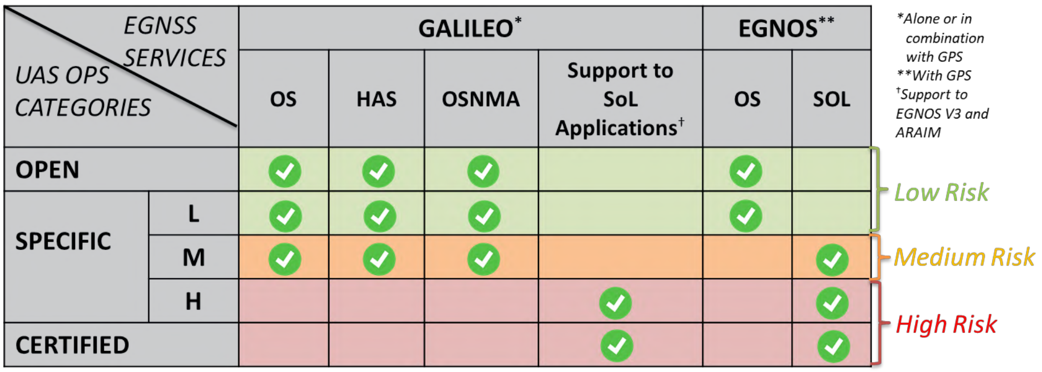
For the Certified category, those (certified) unmanned aircraft flying according to Instrument Flight Rules will be subject to the same airspace usage requirements and operating procedures as manned aircraft and these are being reviewed to ensure that all the particularities of the drones are properly covered. Much of the previous section 3.4.3 on manned aviation would therefore equally apply to those unmanned aircraft in terms of PNT. This is the category with the most demanding PVT performances especially for Beyond Visual Line of Sight (BVLOS) operations.

On the other hand, drones flying in the Open and Specific categories are currently not subject to specific navigation performance requirements. It is the responsibility of the UAS operator to ensure that externally provided services, which are necessary for the safety of the UAS operations such as GNSS services, reach a level of performance that is adequate for the operation and are kept for its full duration. However, in the Specific category, the applicant needs to define the risk area when conducting the operation, which includes the operational volume composed of the flight geography and the contingency volume. **To determine the operational volume the applicant should consider the position keeping capabilities of the UAS in 4D space (latitude, longitude, height, and time)** and hence the accuracy of the navigation solution should be considered and addressed in this determination, and **depending on the operation (SAIL level), the integrity may also play a key role in ensuring that the GNSS PNT solution is trustable for the intended operation as an input to the drone's navigation system**.

In this sense major steps have been taken by the European Commission and EASA to further support the drone industry with the publication of clear regulations laying the foundation for current and future innovative operations. The adoption of the first regulatory framework for **U-space** (Commission Implementing Regulations (EU) 2021/664, 2021/665 and 2021/666) sets out provisions for UAS operators, U-Space Service providers (USSP), providers of Common Information Services (CIS) and impacted ANSPs, establishing some U-space mandatory services to be provided wherever a U-space airspace is designated. Member States are responsible to determine the performance requirements in a designated U-space airspace, based on an airspace risk assessment before the U-space designation.

There are currently no harmonised U-space airspace usage requirements in terms of navigation capabilities and performances but it is envisaged that **GNSS can play a role in improving the U-space services** since services such as the Network Identification, Geo-awareness, Flight Authorisation and Traffic Information can benefit from the use of GNSS, also in support the implementation of the **Urban Air Mobility (UAM) concept**.

Despite GNSS already supporting UAS operations and contributing to U-space services and Urban Air Mobility, the European Commission is working on further facilitating the use of EGNSS services for drone operations according to an internal **Roadmap for the use of EGNSS Service in drones** which will support the emerging drone market with the development of adequate EGNSS services. First, the roadmap considers the following allocation of EGNSS services to drone operations:



UAS OPS CATEGORIES / EGNSS SERVICES		GALILEO*				EGNOS**		
		OS	HAS	OSNMA	Support to SoL Applications†	OS	SOL	
OPEN		✓	✓	✓		✓		Low Risk
SPECIFIC	**L**	✓	✓	✓		✓		Low Risk
	M	✓	✓	✓			✓	Medium Risk
	H				✓		✓	High Risk
CERTIFIED					✓		✓	High Risk

*Alone or in combination with GPS
**With GPS
†Support to EGNOS V3 and ARAIM

Figure 18 – EGNSS services allocation to drone operation categories

Since UAS operations comprise an immense range of use cases and operational environments, a stepwise methodology is followed which addresses first low-risk operations (which have almost reached today an acceptable level of maturity), then medium-risk operations (which are demanding in terms of requirements but are about to bloom due to an improved regulatory and standardisation support) and finally the higher risk operations (which support the most demanding future applications like for example Air Taxis within the UAM concept):

- For low-risk operations, EGNSS information and support to UAS Users (e.g., websites, helpdesk) will be improved.
- For medium-risk operations, an EGNSS service provision model based on the existing or planned EGNSS services, including also dedicated SDD commitments if needed, and an EGNSS navigation operational/integrity concept will be developed.
- For high-risk operations, dedicated EGNSS services for drones will be created, with the aim to declare dedicated SDD commitments.

Alongside a support for EGNSS standardisation will be provided, mainly through EUROCAE which is already proposing a variety of supporting documentation via its group WG-105. In particular, the following GNSS initiatives are ongoing:

- ED-301 '**Guidelines for the Use of Multi-GNSS Solutions for UAS Specific Category – Low Risk Operations SAIL I and II**' covering specific aspects of the use of GNSS for low-risk operations and published in 2022.

- Development of the '**Guidelines for the use of multi-GNSS solutions for UAS: Medium Risk**' to extend the use of GNSS by UAS operators in the frame of the Specific Category to medium-risk operations, for publication in 2024.

Finally, the European Commission funds a number of projects under Horizon 2020 and Horizon Europe programmes to study navigation performance of unmanned aircraft operations (e.g., REALITY or EGNSS4RPAS), providing valuable inputs to standardisation and regulatory initiatives.

3.4.5 Maritime and inland waterways navigation

IMO (International Maritime Organization) sets out the basic Required Navigation Performance parameters for the World Wide Radio Navigation Systems (WWRNS) in IMO Resolution A.1046(27). IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) defines the appropriate standards, recommendations and guidance material for maritime authorities considering the established requirements and maritime regulations, referenced in the IMO's Safety of Life at Sea (SOLAS) convention. Since maritime is a global industry, those standards, recommendations, and guidelines are key. **Galileo is recognised as a component of the WWRNS since 2016,** while IMO stated in June 2017 that **SBAS** is not in the scope of IMO Resolution A.1046(27) and hence it does not require IMO recognition to be used in maritime.

IMO resolution A.915(22) provides a **list of maritime applications**, regulated or not, **requiring the knowledge of the craft position or velocity for general navigation or any other purpose**. This resolution, which might require update in the future, is the internationally agreed reference summarising the positioning needs of the maritime users, in particular **IMO defines the maritime requirements for GNSS**, defining general, operational, institutional, and transitional requirements.

Waterborne transport takes place in different environments or phases of navigation:

- **Ocean navigation**: beyond the continental shelf and more than 50 nautical miles from land.
- **Coastal navigation**: above the continental shelf or within 50 nautical miles from shore.
- **Harbour approach and entrance, and inland waterways**: normally takes place in restricted waters, where ships must navigate through well-defined channels.

Waterborne navigation requirements for general navigation depend on the phase of navigation (further information in EUSPA maritime and inland waterways user needs report).

The IMO started to develop at the Maritime Safety Committee (MSC) in 2006 the **e-Navigation concept** as 'the harmonised collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment'. This concept is based on robust PNT services offering sufficient redundancy. Resilient PNT is one of the seven pillars of the IMO e-Navigation architecture. The e-Navigation concept is expected to spread the use of multi-constellation GNSS receivers and ensure resilience using alternative systems.

For the **Maritime Navigation**, Directive 2002/59/EC Annex III (as amended) is establishing a Community vessel traffic monitoring and information system, with Automatic Identification System **(AIS) data collected by satellite** as one of the interfaces of the central SafeSeaNet system, hence as **a source of data for the electronic messages including information such as the ship's position**. It is an important element for vessel traffic monitoring and thus to help enhancing the safety and efficiency of maritime traffic.

With regard to **Security**, IMO issued high level Guidelines on maritime cyber risk management (MSC-FAL.1/Circ.3) complemented with further recommendation from shipping associations, International Association of Classification Societies (IACS) and International Association of Ports and Harbours (IAPH). The guidelines on cyber security on board ships provided by the shipping associations, underscores that […] *cyber incidents can arise as the result of loss of or manipulation of external sensor data, critical for the operation of a ship. This includes but is not limited to Global Navigation Satellite Systems* (GNSS) […] *A cyber incident can extend to service denial or manipulation and, therefore, may affect all systems associated with navigation*. **Authentication and integrity of accuracy of the vessel position is needed** to support alerting the bridge of a situation of risk.

The EGNSS programmes are working in different initiatives to provide additional information for both integrity and authentication to be used in maritime (see 3.3.2.2 for the various phases):

- **EGNOS corrections use** in RTCM format **via MF-radio beacons and AIS VDL Message 17** is already enabled and IALA Guidelines G-1129 explain how to implement this retransmission.
- With respect to **integrity**, developing a first **EGNOS maritime service that together with RAIM** will enable more accurate positioning including alerts to the bridge. IALA Guidelines G1152 provide coastal Maritime Authorities with information on how SBAS will be used as a maritime service. A new shipborne receiver test standard is under preparation within IEC for SBAS receivers (IEC 61108-7) and is expected to be published in 2023.
- With respect to **authentication**, two projects funded under fundamental elements GSA/GRANT/02/2019 are implementing Galileo Open Service Navigation Message Authentication (OS NMA) for shipborne receivers.

Related to these initiatives, there is a need to **update certain standards and regulations**:

- IMO Res. MSC233 (82) adoption of the performance standards for shipborne Galileo Receiver Equipment: IMO NCSR is currently discussing a new approach to simplify these performance standards. IEC 61108-3 on Maritime navigation and radiocommunication equipment and systems will then include in the update specific recommendations for shipborne GALILEO receiver equipment, normally in 2023.
- A new work item will be requested in IMO to develop performance standards for **DFMC SBAS + ARAIM.** The work could be finalised in 2025, and consequently a new IEC test standard for DFMC SBAS should be developed with the objective to finalise it 2 years later.
- Commission Implementing Regulation (EU) 2022/1157 on design, construction and performance requirements and testing standards for marine equipment: to include new and updated performance and test standards for shipborne receivers, both for Galileo and DFMC SBAS + ARAIM. It should happen in the next yearly update after the availability of standards.

In terms of resilient PNT services, International Association of Lighthouse Authorities (IALA) with a key contribution of several Member States is working in a **back-up system for coastal and harbour areas called R-MODE** (or Ranging Mode) using signals from Medium Frequency (MF) Radio beacon stations and AIS/VDES stations (AIS – Automatic Identification System / VDES - VHF Data Exchange System). R-MODE Baltic2 project, co-funded by the European Union under Interreg Baltic Sea Region initiative, set-up a test bed in the Baltic Sea (see section 5.3.5 for more information on R-MODE). IALA Guidelines G1158 explain that **GNSS timing can be used** at shore level as one of the sources of timing to provide the synchronisation of the VDES signals required **for R-MODE**. This requires a reassurance that the GNSS signal, as received by the stations, is not spoofed (e.g., by using encrypted GNSS signals and verifying the GNSS integrity in the stations).

EU-funded research and innovation on civil maritime security has also exploited PNT and GNSS services for developing capabilities for security of maritime assets and individuals against natural or international threats, as well as the capabilities of Coast Guards and for civilian tasks of Navies.

Navigation in Inland Waterways **requires position accuracy, including the vertical domain**, used to calculate clearance of bridges, locks etc. and to monitor traffic situation. To increase the performance of GNSS, IALA DGPS stations were established to some extent also to cover the inland waterways. In addition to this, distribution of DGPS data through AIS message 17 is done in many areas with the help of Inland AIS base stations, available to vessels that are equipped with an Inland AIS transponder (which is compatible with the maritime AIS transponder).

In comparison with maritime navigation, inland navigation faces more **difficulties related to blocking of satellite signals** due to land shadowing, mountains, or obstructions from man-made objects such as bridges and locks. Unfortunately, in locations where highest position accuracy is required, also GNSS signal blocking is likely to occur (e.g., when a ship enters a lock). In terms of integrity, accuracy and reliability, the inland navigation users would therefore benefit from **multi-constellation navigation**, because more satellites are available.

Inland navigation users could benefit from the **High Accuracy Service** from Galileo and future dedicated **EGNOS services** for maritime use if the positioning equipment on board of inland vessels is installed properly. However, higher levels of automated inland navigation will require **additional near-field sensors** such as LIDAR and Radar sensors on top of the GNSS sensors. **Multiple antennas processing** could be also exploited to increase navigation robustness and safety.

Directive 2005/44/EC (RIS Directive) on harmonised river information services on inland waterways contains a recommendation for the use of satellite positioning technologies. Commission Implementing Regulation (EU) 2019/838 on technical specifications for vessel tracking and tracing systems contains **detailed requirements and technical specifications** for vessel tracking and tracing systems in accordance with the provisions in the RIS Directive, respecting the following principles:

- The definition of the requirements concerning systems and of standard messages as well as procedures so that they can be provided in an automated way.
- The differentiation between systems suited to requirements of tactical traffic information and systems suited to requirements of strategic traffic information, both regarding positioning accuracy and required update rate.
- The description of the relevant technical systems for vessel tracking and tracing such as Inland AIS (inland automatic identification system).
- Compatibility of data formats with the maritime AIS system.

Directive 2005/44/EC (RIS Directive) is currently being revised, with a view to adoption in 2023. The revision will consider the work of the European Committee for Standards for Inland Navigation (CESNI), which has adopted the first set of RIS Standards in April 2021 (European Standard for River Information Services, ES-RIS 2021/1). ES-RIS 2021 is a reproduction of the currently applicable technical specifications contained in the Implementing Regulations (EU) under the RIS Directive. Future evolutions of the technical specifications, including the ones on vessel tracking and tracing systems, will be covered by the two-yearly revisions of the ES-RIS, and set into force through secondary legislation under the revised RIS Directive. **Specific provisions on PNT and GNSS may also be covered by the ES-RIS in the future**.

In addition, the Inland AIS test standard mandate all the IEC standards included in the series 61108 for the internal GNSS receiver. Today those includes Galileo (part 3) and enables the use of EGNOS once part 7 is published (expected by mid-2023). The use of EGNOS corrections transmitted in RTCM format via VDL Message 17 is already enabled.

Finally, inland waterways transport is evolving and benefiting from emerging technologies that lead to a safer, digital, and more sustainable sector. Autonomous vessel operations will create new business opportunities (also for Maritime Navigation), as well as new challenges, supporting the digitalisation and sustainability challenges of the EU. The European Commission intends to launch in 2023 a **preparatory action on EU Space Data for autonomous vessels in Inland waterways** with a duration of 3 years to assess how EU Space Data from Galileo, EGNOS and Copernicus can be key enablers of this transformation, by facilitating reliable and robust positioning information and harmonised images of the fairways and environment, needed for safe and green autonomous operations.

3.4.6 Road transport

The **success of satellite positioning in vehicle application platforms and portable navigation devices** thanks to the accurate position and advanced navigation they deliver has been reinforced lately by the appearance of user friendly navigation apps and maps on smartphones as described in the EUSPA road user needs report.

The **dominant place of GNSS road applications** in the market is confirmed by public authorities' decisions and the advent of connected cars, which, combined with permanent short-range communication between vehicles, other road users and infrastructure (vehicle to everything – V2X communications), offer an almost unlimited series of applications which will improve both road safety and traffic efficiency. Moreover, GNSS coupled with other on-board sensors and 3D mapping will play a key role in **autonomous vehicles** due to the very demanding performance requirements in terms of positioning accuracy, availability and robustness required.

The **smart tachograph**, introduced by Regulation (EU) No 165/2014, is an evolution of the digital tachograph, which notably includes a connection to a GNSS receiver, a remote early detection communication facility and an interface with intelligent transport systems. The use of tachographs connected to **GNSS** is an **appropriate and cost-efficient** means of automatically recording the position of a vehicle at certain points during the daily working period to support officers during controls. The **technical specifications** of the smart tachograph were laid down in Commission Implementing Regulation (EU) 2016/799, and smart tachographs have been installed in newly registered vehicles since 2019.

The technical specifications were updated in Commission Implementing Regulation (EU) 2021/1228 to cover the registration of starting and ending positions of the working days of drivers of commercial vehicles, and also border crossings and loading and unloading operations. GNSS and border-crossing geofencing allow enforcement authorities to control more efficiently international transport operations of road undertakings against EU market and social rules. This **second version** of the smart tachograph is also expected to **use the Galileo OSNMA service,** once it is declared operational. This tachograph will start being rolled out in newly registered vehicles in August 2023. All vehicles engaged in international transport operations and in the scope of the Regulation (EU) No 165/2014 will be retrofitted with a second version smart tachograph by August 2025 at the latest.

Regarding **Electronic Tolling, GNSS for Road User Charging**, which consists of charging a user (i.e., vehicle) based on its reported position, is regulated under Directive (EU) 2019/520 on the interoperability of electronic road toll systems. The Directive allows **satellite-based tolling** for heavy-duty and light-duty vehicles, which permits the removal of physical toll stations in highways, eliminating also queues and saving time for the final user, while granting users' privacy through data anonymisation. From October 2021, all new electronic toll systems brought into service using satellite positioning shall be compatible with EGNOS and Galileo. In addition, from 2028 all new electronic toll systems for passenger cars shall be compatible with GNSS.

As regards **Intelligent Transport Systems (ITS)**, Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport states that for ITS applications and services, for which accurate and guaranteed timing and positioning services are required, satellite-based infrastructures or any technology providing an equivalent level of precisions should be used, such as those provided by EGNOS and Galileo. Several Delegated Regulations adopted within this framework, such as Commission Delegated Regulation (EU) 2015/962 with regard to the provision of EU-wide real-time traffic information services, organise the access to and exchange of data generated thanks to accurate positioning, including in-vehicle generated data.

The Commission proposal (COM (2021) 813) for the revision of Directive 2010/40/EU proposes to ensure the compatibility of ITS applications and services, which rely on timing or positioning, with at least the navigation services provided by EGNOS and Galileo, including OSNMA.

In 2020, two **relevant PNT standards** were released for ITS secure communications (CEN/ISO TS 21176) and vulnerable road users (ETSI TS 103 300-1, ETSI TS 103 300-2, ETSI TS 103 300-3). DATEX II is the data exchange standard for ITS stations exchanging traffic information between public authorities and service operators: traffic incidents, road works, etc. Since 2021, DATEX II v.3.2 includes a location data model requiring the registration of GNSS authentication.

Regarding **eCall**, Regulation (EU) 2015/758 lays down the type-approval requirements for the deployment of the eCall in-vehicle system based on the 112 service. The provision of accurate and reliable positioning information is an essential element of the effective operation of the 112-based eCall in-vehicle system. According to this Regulation, manufacturers of eCall shall ensure that the **receivers** in the 112-based eCall in-vehicle systems are **compatible** with the positioning services provided by the **Galileo and the EGNOS** systems. The Commission Delegated Regulation (EU) 2017/79 specifies testing methods and performance requirements for the type approval of GNSS.

In 2018, UN Regulation 144 entered into force establishing a harmonised type approval mechanism of eCall systems, devices or components to be valid in more than 50 countries, including Japan, Korea and Russia. Compatibility with GPS, GLONASS, Galileo and all existing SBAS is required.

In 2021, the European Commission started the works to update the current eCall specifications, both for vehicles and public safety answering points, to adapt the current legal framework to the evolution of the telecommunications networks towards packet switched networks.

For **Safety Automotive Systems** and In the frame of the new General Safety Regulation (EU) 2019/2144 for automotive vehicles, the Commission Delegated Regulation (EU) 2021/1958 on Intelligent Speed Adaptation (ISA) systems employing a combination of a camera system, GNSS and digital maps, require that where such a system is enabled with positioning capabilities, it shall be **compatible at least with Galileo and EGNOS.**

In 2021, UN Regulation 155 entered into force establishing uniform provisions concerning the cyber security management in autonomous vehicles. GNSS spoofing is considered a threat and the use of authenticated messages is required as mitigation.

The CEN/CENELEC EN 16803 standard established the GNSS test procedures and methodologies for the establishment and assessment of performances in highly demanding road applications, such as autonomous vehicles. The publication of a compatible ISO standard is still needed.

Finally, over the next years, the **digitalisation of enforcement practices** can likely offer more possibilities for the use of EGNSS, and lead to more efficient controls of vehicles and drivers. Indeed, enforcement of rules in road transport is key to ensure road safety and a well-functioning market, be it driving and rest times, weights, and dimensions of vehicles, posting of drivers, possession and compliance with transport authorisations, licences and permits, etc. For example, precise and reliable location information could contribute to the management of priority goods combination with electronic freight transport information (eFTI) in customs and border controls.

Related to road, the follow **standards** would facilitate the introduction of EGNSS services:

- Update 3GPP standard for DFMC GNSS signal dissemination through Mobile Network.
- Test Standard for GNSS + HAS through RTCM SC134.

3.4.7 Rail transport

The **European strategy for railways** aims to make the rail network open and interoperable, which includes replacing national train control systems with the **European Rail Traffic Management System / European Train Control System (ERTMS/ETCS)**, a standardised system developed specifically for the needs of European railways. This system does not use GNSS in its current form, as its core architecture has been designed in 1989/90. Different initiatives have been launched to include GNSS in ETCS, due to its potential to reduce trackside infrastructure by eliminating **Eurobalises** used as position reference markers. This would not only lower the cost of signalling, but also increase availability, reduce engineering and maintenance requirements and its exposure to theft, vandalism etc.

Additional new functionalities are also being investigated for ERTMS/ETCS which could rely heavily on GNSS, such as **train integrity monitoring**, a function within the ERTMS Level 3 system which thanks to the absolute positioning of trains would enable to reduce the separation of the trains, to optimise the traffic and to have positive effects on the environment.

The **main technical challenges** for exploiting GNSS on railway lines lie in the environment, which differs significantly from the aviation and maritime applications. The major differences are a limited and continuously changing satellite visibility, signal attenuation, electromagnetic interference, and significant multipath. In some locations, such as in urban and mountainous areas, these effects can all appear simultaneously. Further information can be found in the EUSPA rail user needs report.

Today, GNSS systems in the railway domain are predominantly used for **non-safety related applications**. Passenger information systems are the main applications, with asset management gaining importance. In the coming years, safety relevant applications, signalling and train control, based on GNSS will be increasingly developed, to complement traditional technologies. Within **safety critical applications**, EUSPA has developed a roadmap for EGNSS adoption in Rail, approved by the main rail and space stakeholders, which summarises the main activities towards EGNSS enabled ERTMS and allows elementary orientation in the activities to achieve this goal.

In 2022, the European Parliament resolution on railway safety and signalling assessing the state of play of the ERTMS deployment pointed out the need to ensure synergies between ERTMS and EGNSS as soon as possible. This is well reflected by the rail sector, which is for instance developing a train localisation onboard unit prototype (Horizon 2020 CLUG project).

The European Commission continues to also investigate the possibilities to use or evolve EGNSS services for rail safety critical applications. At present, two mission studies are on-going and aim to clarify the parameters of a rail specific EGNSS service that could satisfy the user requirements for rail signalling and ERTMS (EGNSS-R, IMPRESS).

The **Technical Specifications on Interoperability (TSI)** define the technical and operational standards which must be met by each subsystem or part of subsystem to meet the essential requirements and ensure the interoperability of the railway system of the European Union. In particular, **the inclusion of GNSS in the Control Command and Signalling TSI is also a prerequisite to enable a wide-scale GNSS adoption for fail-safe train localisation in European Union**. The last modification of this document was adopted in June 2019 and the next release is foreseen during 2023. Further, a maintenance release of the TSI is foreseen in 2026, with an updated version containing new functionalities in 2028/2029.

3.4.8 Agriculture

The projected growth of the world's population to 9.7 billion by 2050, coupled with a higher caloric intake of increasingly wealthy people and the ensuing increase of food demand, renders the intensification of food production imperative as described in the EUSPA agriculture user needs report. There is a need for a comprehensive global food security strategy where **information technology-enabled solutions** play a key role. **With GNSS holding a predominant position**, other technologies such as GIS (Geographic Information System), remote sensing through satellites or UAS (Unmanned Aircraft System), optical sensors for nitrogen content and canopy condition, machine vision systems, gamma-radiometric soil sensors, etc. have been deployed across a wide range of applications. The utilisation of the various enabling technologies and the combination of the different types of data they generate, has given rise to **Precision Agriculture (PA)**, which has demonstrably contributed to increasing yield and productivity while controlling costs and reducing the environmental impact of agricultural activities.

The market uptake of **GNSS-enabled Precision Agriculture** applications will increase along the need for increased food production. Accuracy will remain the most fundamental GNSS parameter for farmers. Reliability, availability, authenticity, and coverage will also have relevance for specific applications. **SBAS-based solutions**, improving the accuracy, integrity, and availability of the basic GNSS signals, are becoming increasingly available in precision agriculture applications, frequently being the preferred option for farmers entering the precision agriculture market. Available over continental scales, free of subscription fees or additional investment costs, SBAS-based solutions are widespread amongst farmers requiring accuracy to sub-metre level. **High accuracy solutions (sub-decimetre)** are needed for automation and are provided by RTK / Network RTK services and real Time PPP services, either commercial or institutional as the Galileo High Accuracy service.

The integration of GNSS positioning in **Farm Management Information Systems (FMIS)** together with the use of additional information coming from various sensors, including Earth Observation, is due to revolutionise precision farming and further driving its uptake. FMIS is a system for collecting, processing, storing, and providing data enabling informed decision-making and management strategy elaboration for farmers. **GNSS links this data to specific geographical coordinates**.

Despite the varying successes and uptake rates of the various technology-driven solutions for agriculture, mainstreaming and extending their adoption require **several technological, economic, and awareness-related challenges to be addressed**. Recently the dedicated Focus Group on Mainstreaming Precision Farming set up by the European Innovation Partnership on Agriculture, has placed on top of their recommendation list the need for 'Farmers and cooperatives to play a major role in innovation and in research on decision support systems and technical solutions to current problems'.

Several initiatives facilitate the adoption of EGNSS in the European agriculture sector.

EGNSS4CAP is a **mobile phone application** for Android and iOS that **digitises procedures for farmers** in the European Union to satisfy their reporting requirements under the current and post-2020 Common Agricultural Policy (CAP) reform.

New rules adopted by the European Commission for the current and upcoming CAP allow a range of modern **satellite-based technologies** to be **used** when administering and controlling **area-based payments**. For example, automatic monitoring procedures employing data and signals from both the

Copernicus and Galileo programmes can be used to reduce the number of on-the-spot checks (OTSC). These procedures are part of the Checks by Monitoring (CbM) mechanism and are applied in a certain number of Member States on a voluntary basis.

For the **new CAP**, the Area Monitoring System (AMS) will be introduced. With that mechanism, all Member States will need to **monitor 100% of area-based payments**. The use of these technologies is a part of the European Commission's ongoing commitment to modernise and simplify the Integrated Administration and Control System (IACS) processes within CAP.

The EGNSS4CAP application will use EGNSS differentiators to enable farmers to provide geotagged photos and LPIS (Land Parcel Identification System) updates that both support and complement a Copernicus Sentinel-based monitoring approach for CAP.

The tool is Open Source, available for free and can be integrated by any Android or iOS developer. Mass market devices such as smartphones and tablets will be able to run the application and use GNSS to provide location and timing of the photo ensuring required accuracy and authentication for reporting to the paying agencies.

The **Farm Sustainability Tool (FaST)** is a digital service platform making available capabilities for agriculture, environment and sustainability to EU farmers, Member State Paying Agencies, farm advisors and developers of digital solutions. FaST will support farmers in their administrative decision-making processes, for farm profitability and environmental sustainability.

EGNSS will be an integral part of FaST as it will permit farmers to combine earth observation data with real-time positioning, as well as communicate geotagged information with the Member State authorities.

Although not considered as a primary source of information for the **Land Parcel Identification System (LPIS),** data collected on site using **GNSS**, **provides valuable contribution** for the LPIS upkeep. Most of the field information using GNSS used for the LPIS, is gathered during the classical on-the-spot checks of the farmer declarations. Moreover, field inspectors are required to report any non-correct reference parcels and the EFA layer. Some Member States are also conducting occasionally more systematic field surveying using GNSS.

The **New IACS Vision in Action (NIVA)** modernise IACS with digital solutions and e-tools, by creating reliable methodologies and harmonised data sets for monitoring agricultural performance while reducing administrative burden for farmers, paying agencies and other stakeholders.

The **UC4a 'Geotagged Photos'** use case of the NIVA project consists in designing and developing an application for mobile devices to facilitate a farmer and/or advisor to upload a geotagged photograph as supporting evidence to scheme applications. This project will exploit novel features of GNSS preventing location spoofing (e.g., authentication within Galileo signal). The App will demonstrate the ways to receive notifications from the supporting system and the ability to notify and guide farmers to successfully locate, line up, frame and capture images for the requested points of interest.

The end user will benefit by having more engagement options with the paying agency. The farmers may reduce on-the-spot inspections if they upload the photographic evidence of activity or clarify the query. The Administration will have an electronic record of the response and a comprehensive profile of agricultural activity in the parcel.

In eco-schemes concerning **precision farming** EGNSS could help farmers to improve nutrients management plans, reduce inputs (fertilisers, water, plant protection products) and improve irrigation efficiency or the monitoring of the use of pesticides by precisely recording the location where the pesticides were spread.

3.4.9 Location-Based Services

The most used navigation device is our mobile phone where PNT is mostly used for Location Based Service (LBS) applications. In a context of global urbanisation and smart city, **GNSS-enabled LBS addresses some of the most immediate economic and societal concerns** such as improvement of work productivity, ease of movement, tracking of people, resources' management and effective services to facilitate consumer interactions (EUSPA Location Based Service user needs report).

GNSS-enabled solutions cover a myriad of applications, including navigation, mapping, GIS (Geographical Information System), geo-marketing and advertising, safety and emergency, sports, games, health, tracking, augmented reality, social networking, infotainment. Several of these applications require stringent horizontal and vertical accuracy levels and authentication of the position (e.g., location-based billing to prevent fraud).

Standardisation activities related to LBS can be divided in **signalling, performance** requirements for positioning including GNSS and A-GNSS (Assisted GNSS), and **testing** procedures. The main standardisation bodies are the 3rd Generation Partnership Project (3GPP), the Open Mobile Alliance (OMA), ETSI TC SES, and CEN-CENELEC.

According to the Commission Delegated Regulation (EU) 2019/320 from 17 March 2022 all **smartphones placed in the European single market** need to offer the option to send handset-derived location information using Galileo signals, in addition to other GNSS, to the closest Public Safety Answering Point (PSAP) **emergency service**. This is to enhance the 112 emergency calls location for faster response times and consequently saving more lives (EUSPA EO and GNSS Market Report 2022 LBS). A large majority of the smartphones already complies with the requirements, which are assessed by notified bodies through conformity assessment procedures, using European Commission provided Guidelines. This functionality is activated on a country-by-country basis depending on the technical and operational readiness of the **Advanced Mobile Location (AML)**.

Two standards for 4G and 5G enabled smartphones, released by 3GPP in 2020 and 2021 (3GPP TS 36.171 version 16.1.0 Release 16 and 3GPP TS 38.171 version 16.2.0 Release 16) *Requirements for support of Assisted Global Navigation Satellite System (A*-GNSS) foresee a 'constellation agnostic' approach (i.e., the system having the satellite with highest signal level, shall be selected by the device manufacturer). This is an important safety step moving from a 'GPS centric approach', irrespectively of the time to first fix provided by other constellations.

Following the **availability of pseudoranges on Android** operating system, the Raw Measurements Task Force aims to bridge the knowledge gap between raw measurement users and industries. In addition, **EUSPA/JRC testing campaigns** are running to evaluate the performance and functionality features specifically aimed at smartphones and other mass market devices.

Finally, the **5G PNT Navigation Task Force** contributes to 3GPP works on PNT and promotes the **inclusion of EGNSS into the 5G PNT ecosystem** to ensure that the technical specifications produced by 3GPP account also for the possibility to **complement EGNSS with 5G**, where GNSS coverage is not available (e.g., indoor) but also for improved positioning accuracy when in nominal conditions. Furthermore, 5G positioning architecture and protocols have been adjusted over the last years to support the delivery of assistance data needed for high-accuracy GNSS techniques (e.g., RTK, PPP, etc.) in both unicast and broadcast with the first products and services starting to emerge both in Europe and US.

3.4.10 Search and Rescue

The objective of Global Search and Rescue (SAR) operations is to quickly locate and help people in distress. Although not all Search and Rescue beacons are GNSS-enabled, there is an increasing trend towards GNSS uptake amongst these beacons.

The COSPAS-SARSAT Programme is an international satellite-based search and rescue distress alert detection system. Currently, the **Galileo SAR service contributes** to this system by swiftly relaying radio beacon distress signals to the relevant SAR crews, using dedicated payloads on-board Galileo satellites and three ground stations deployed across Europe (refer to 3.2.7 for further information). The SAR service requires SAR enabled receivers (beacons).

The availability of the Galileo SAR service benefits all those sectors in which due to the nature of their operations the lives of people is at stake, notably maritime and aviation.

For **maritime**, the IMO established in 1988 the Global Maritime Distress and Safety System (GMDSS), with the intention to always allow vessels send and receive maritime safety information. It reached operational status by 1997.

Ships need to be equipped with Emergency Position Indicating Radio Beacons (EPIRBs) and Personal Locator Beacons (PLBs) which transmit, once activated, the necessary information to emergency authorities. The AIS-SART (Search and Rescue Transmitter) and AIS-MOB (Man Overboard) beacons not only transmit the position of the person in distress, but also share this location through the Automatic Identification System (AIS) with nearby vessels, by pinpointing an AIS distress signal onto the nearby vessels Electronic Chart Display Information System (ECDIS).

In **aviation**, following the tragedies of Air France 447 and Malaysia Airlines 370 and given the time taken to locate the aircraft, ICAO established the Global Aeronautical Distress and Safety System (GADSS) which ensures that aircraft are tracked and that their latest known GNSS derived position is always recorded, maintaining an up-to-date record of aircraft progress. Under the current aircraft tracking standards and recommended practices (SARPs), aircraft under normal flight conditions need to be tracked every 15 minutes. The latest update of ICAO Annex 6 requires autonomous position reporting every minute when the aircraft is in distress. The standard for the distress tracking element of GADSS will be applicable on 1 January 2025 to aeroplanes with a first individual Certificate of Airworthiness (CofA) on or after 1 January 2024.

Aircrafts need to be equipped with Emergency Locator Transmitters (ELTs) or Personal Location Beacons (PLB) that help Search and Rescue operations in the event of an incident. In line with requirements in ICAO Annex 10 (and standards set in ICAO Annex 6) as well as the implementation of the GADSS, many ELTs make use of GNSS to report their position when triggered.

Finally, SAR services are also extensively used on **land** where climbers and hikers are advised to equip themselves with a PLB in case they find themselves in distress.

More information about Galileo SAR is available at the EUSPA webpage. EUSPA EO and GNSS Market Report 2022 contains information on the SAR related market , and the EUSPA GNSS User Technology Report provides an overview of the existing technology.

3.4.11 Mapping and Surveying

The mapping and surveying market in general and its use of GNSS, are expected to show significant growth in the coming years especially in regions of the world where there are no alternative legacy systems or dense geodetic ground networks. Significant growth is also expected in regions with intense construction activity, where the importance of cadastral surveys will also increase as a function of the increasing GDP and population. In this context, GNSS-enabled surveying addresses some of the most immediate economic and societal concerns such as increased urbanisation, increased demand for hydrocarbons and modernised transportation needs as described in the EUSPA surveying user needs report.

GNSS-enabled solutions cover a wide range of applications including cadastral surveying (delineation of property boundaries), construction surveying (precise setting out of the buildings and infrastructure), mapping (charts that contain points of interest and are typically integrated in Geographic Information Systems), mine surveying and marine (offshore and hydrographic) surveying.

However, the role of the traditional GNSS surveying is undergoing a rapid transformation thanks to the integration of **emerging applications**, such as optical, multispectral or LiDAR (Light Detection and Ranging), terrestrial laser scanning, UAS (Unmanned Aircraft System), IMU (Inertial Measurement Unit), SLAM (Simultaneous Localisation and Mapping), AR (Augmented Reality), mobile and crowdsourced mapping. In addition, these emerging geomatics applications are mainly focusing the implementation of solutions directly in the cloud.

Thanks to digitalisation, **Building Information Model (BIM)** and **Geographic Information Systems (GIS)** are now integrated into a single holistic environment to produce digital twins. The process of accurate 3D modelling – common for both – is leveraged by **high-precision GNSS location data**. When stored and processed in the cloud, the GNSS, GIS and BIM information enable stakeholders in the whole construction industry to remotely manage data everywhere and produce better building/infrastructure designs with long-term savings.

Another example is urban planning. SLAM technology, with its laser/IMU/camera integration, and portable laser scanners have opened a huge field for detailed realistic modelling inside buildings. When combined with GNSS receivers, these systems are providing seamless indoor-outdoor transition.

As many new methods and tools arise, so does the **need for well-defined requirements and standards**. Within mobile mapping systems, a set of standards would frame the fusion of GNSS with LiDAR, optical cameras, inertial, laser and odometer instruments. Other key areas requiring stringent requirements and standards are seamless indoor-outdoor positioning and PPP-RTK. The recent advancement of augmented reality applications that rely on GNSS accuracy and availability would also benefit from standards.

For mapping and surveying's stringent accuracy requirements (down to cm or mm-level) augmentation services such as **Real Time Kinematic RTK**, **Precise Point Positioning PPP** and the recently emerged PPP-RTK is of paramount importance. Both RTK and PPP multi-GNSS corrections are supported in the standard Radio Technical Commission for Maritime Services (RTCM) protocol, either for a single reference station or network (NTRIP) or PPP.

PPP-RTK implementation within the RTCM is not available yet. As a result, there has been a strong push for the standardisation of PPP-RTK corrections via new messages within the RTCM protocol while, in the meantime, various industry stakeholders and scientific initiatives proposed other protocols or standards (e.g., IGS, Sapcorda, 3GPP, etc.).

To overcome the challenges regarding the lack of availability, quality, organisation, interoperability, accessibility, and sharing of **spatial information**, common to many sectors and various levels of public authority in the Europe, the EU adopted the INSPIRE directive (The Infrastructure for Spatial Information in the European Community). INSPIRE will enhance the **sharing of environmental spatial information** among public sector organisations and better facilitate public access to environmental information across Europe. Mapping and surveying, which utilise geo-data collection services and tools, including those EGNSS-based, are directly linked to INSPIRE.

On this basis, it is essential to ensure the ability to combine spatial data and services from different sources (data interoperability) across the EU in a consistent way without additional efforts of humans or machines. The data interoperability in INSPIRE is assured, amongst others, by **mandating the use of a common coordinate system**, the **European Terrestrial Reference System 1989 (ETRS89)**. This ensures that geospatial data, derived from EGNSS, is fully compatible and integrated into end user applications, leading to accelerating the use of EGNSS.

Machine Control is important and growing part of the survey market. As reported by the **EUSPA Report on User Needs and Requirements Mapping and Surveying**, the most important target markets are **construction** and **mining** sector (e.g., control and semi-automatic guidance of vehicles in earth-moving machines or mining equipment) where centimetre-level accuracy is necessary to increase productivity and lower the cost. Recently dry **port operations** become a new market where unlike the other two segments where machine control is implemented by the vehicle manufacturers, port operations are implemented by the crane producers integrating hardware with the logistics and port management software. Its main advantages consist of managing vessel load, logistics of loading, increased operational speed and safety. This, combined with use of GNSS and different PNT systems creates a unique European Expertise.

The **Machine Directive (2006/42/EG)**, which sets requirements for machines, safety components, lifting accessories (such as chains and ropes) and other related products, is the widely used by EU manufacturers to ensure a common safety level in the machinery placed on the market and to maintain Intellectual Property Rights (IPRs) within EU.

3.4.12 Precise Timing and Synchronisation (finance, power grids, communication)

Electricity transmission, telecom networks operation, timestamping of financial transactions, air traffic management systems, transportation systems, satellite platforms, water and wastewater systems, scientific applications (astronomy, particle physic, geophysics, metrology), digital TV broadcast, LTE small cells networks – femto, pico and microcells -, Internet of Things (IoT) are only a few examples of the **myriad of applications relying on GNSS for timing and synchronisation purposes** (further information can be found in the GSC time and synchronisation user needs report and the GSC GNSS User Technology Report).

Although relatively unknown to the public, the **timing and synchronisation capability offered by satellite navigation** systems has become **essential for critical infrastructures**. The **robustness and resilience in the timing and synchronisation services are key** to avoid serious disruptions of the critical infrastructure's operation. Moreover, since infrastructures in Europe are highly interwoven, the resilience increase of the network cannot be achieved by a Member State acting alone.

Galileo, used as primary source of timing information or as a redundancy solution, will **contribute** to a **more resilient GNSS timing service** by improving both the timing service availability (bringing another independent constellation) and providing several added values such as authentication, which increases the resilience against spoofing.

EGNOS offers time information obtained from GEO satellites or via the terrestrial EDAS service, allowing users to access data online in real time and through two different channels.

In the EU, a major step was the formal creation of a stand-alone **Galileo Timing Service** as part of the mission of the Galileo Second Generation, which leverages on the intrinsic timing capabilities of Galileo as a GNSS System and brings in additional features to better fulfil the specific needs of the timing and synchronisation users:

- **High Availability** of the Timing Service as a whole.
- **Improved Accuracy** for all timing parameters.
- **Dedicated requirements** for the Galileo System Time (GST), making it a very performing reference for synchronisation applications.
- **Galileo Timing Service Monitoring function**, that will significantly reinforce the Timing Service robustness and the confidence in the timing solutions obtained through Galileo. Thanks to the monitoring function, users will be informed through specific flags of faults that might impact the timing service levels' compliance. This particularly relevant for Critical Infrastructure applications.

The Galileo Timing Service concept also includes the development of a **Standard for Galileo Timing receivers.** This Standard will ensure the correct contribution of the user receiver as a fundamental piece for the end-to-end performance. It will also include the implementation of local barriers, such as T-RAIM (Timing RAIM), to further improve the overall robustness. The development of this Standard, the first ever GNSS timing receiver standard, is formally ongoing within CEN-CENELEC.

Finally, Precise Timing is also provided by non-GNSS technologies which further enhance or act as back-up of the GNSS-based timing services, such as longwave systems (section 5.2.7) and emerging technologies (section 5.3). The provision of Alternative Timing is already commercially available in the European Union, as confirmed by a 2022 study conducted by the European Commission. Mature Alternative Timing services exist in the market which **distribute** precise time over long-distances while the EU has a unique distributed network of National Metrology Institutes (NMIs) that can be used to **generate** precise time synchronised to UTC(k).

3.4.13 Space users

The **GNSS market for space is evolving extremely fast** over the last decade, resulting in a deep paradigm shift 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, which coupled with important technological advances, lead to, and increase number of satellites and space services. While entering the third millennium, about 800 satellites were actively orbiting the Earth. Twenty years later, this number now exceeds 3 000 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 mega constellations systems on Low Earth Orbits (LEO) is a marker of this new era.

With satellites manufactured in batch, launches occurring almost every day, equipment being mass produced and processes being industrialised, the space environment is progressively considered as a commodity and **spaceborne GNSS receivers are increasingly common** and relevant for space users, from LEO altitudes (i.e., 300 km) up to Moon Transfer Orbit (MTO).

Spaceborne GNSS receivers are **not fundamentally different from classical GNSS receivers**. They perform the same operations and provide the same PVT services, but they must address **specific constraints of the space environment** (e.g., high dynamics, reduced signal power and visibility, solar radiation). Depending on the mission expected from the spacecraft, the role of the embedded GNSS receiver varies. While they can be used as a guidance and navigation control subsystem (i.e., for precise orbit determination, attitude determination or synchronisation purposes), they can also be used as one of the payloads directly serving the mission objectives (e.g., radio occultation measurements).

The **benefits of GNSS-based solutions aboard spacecraft** range from the reduction of spacecraft's dependence on ground-based stations to improved navigation performances. 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 for space users of GNSS solutions that would benefit of the combined use of existing global and regional navigation systems, the International Committee on Global Navigation Satellite Systems (ICG) has issued The Interoperable GNSS Space Service Volume to reap the benefits of the existing global and regional navigation systems when used together to provide improved capacities.

In the EU, the main initiative to facilitate the use of Galileo by space users is the formal definition of a **Galileo Space Service Volume** as part of the mission **for the Galileo Second Generation** (see 3.2.1.2 for further information). This will ensure that all the required activities are implemented, to allow Galileo commitments on the level of performance that space users can achieve when using Galileo signals in space. It is important to recall that **Galileo signals are the most suitable for space users** amongst the GNSS systems thanks to the higher altitudes of the Galileo satellites and to the authentication capabilities offered by the Galileo Open Service Navigation Message Authentication.

Finally, the **validation** of the performance **of precise orbit determination from Galileo signals** in a typical configuration of low-cost receiver is on-going in the frame of Horizon 2020 In-Orbit Demonstration/Validation (IOD/IOV).

More information can be found in the EUSPA space user needs report.

3.4.14 Security and Defence

Security and military operations rely heavily on space-based data and space-enabled capabilities, including dual-use ones, to provide secure, robust, reliable, and highly performant services in an evolving threat environment. The Strategic Compass for Security and Defence recognises space as an operational domain and calls for an EU Space Strategy for security and defence.

The **EU Security Research and Innovation Programme** and the Research and Development (R&D) actions of the Cluster 3 'Civil Security for Society' of Horizon Europe, and its precursors in Horizon 2020, FP7 and Preparatory Action for Security Research (PASR) which has funded over 700 projects since 2004, promote cooperation and include the development and exploitation of PNT / GNSS for security practitioners such as law enforcement, border management, maritime security, protection of critical infrastructures and disaster resilience. **Horizon Europe Cluster 3's security projects mandate the use of EU Space Programme whenever developing relevant PNT capabilities.**

The R&D actions of the **European Defence Fund (EDF)**, and the European Defence Industrial Development Programme (EDIDP) and the Preparatory Action on Defence Research (PADR), include the development of Galileo and PNT technologies for military users. The EDF promotes cooperation among companies and research actors of all sizes and geographic origin in the EU, for the sake of state-of-the-art and interoperable defence technology and equipment. It also aims to improve PNT performances and resilience to achieve the goal of 'uninterrupted PNT access worldwide'.

From the many awarded projects, the following R&D actions are of relevance for PNT services:

- **GEODE - Galileo for EU defence**, EDIDP 2019 - will prototype, test, and qualify multiple Galileo PRS enabled PNT solutions for defence specific requirements and applications (7 PRS Security Modules, 9 PRS receivers, 4 GPS/Galileo PRS compatible Controlled Radiation Pattern Antennas) and a European PNT test & Qualification Facility. PRS infrastructure will also be developed to ensure the availability of the security assets required for operational testing of the receivers. Military operational field-testing will be organised on Naval and Land platforms, RPAS, Timing and Synchronisation system in multiple Member States.
- **QUANTAQUEST - Quantum Secure Communication and Navigation for European Defence**, PADR 2019 - will contribute to the applicability of quantum technologies in the military field and to the strategic autonomy of Europe. Navigation and timing will be achieved through a fully autonomous sensor based on cold atom chip and photonic integrated circuit that provide the required performance and portability. Secure communication will be improved by a new modulation scheme to implement Quantum Key Distribution. Field operation compatibility will be ensured with a free space approach. Quantum interface will be implemented as the opening gate to a quantum network of sensors.
- **NAVGUARD (Advanced Galileo PRS resilience for EU Defence**, EDF 2021) will strengthen the Galileo PRS resilience through new ground and space-based systems. It will develop a European NAVWAR capability relying on GNSS spectrum surveillance based on ground and space-based systems to detect illegitimate activities in GNSS frequency bands and geo locate their sources. The project will also design, prototype, and test an Information management subsystem together with a user interface to establish a situational awareness picture. Five different PRS mobile receivers will contribute to the overall NAVWAR capability together with an in-orbit demonstration of a PRS space-based augmentation system.

- AI-ARC (Artificial Intelligence based Virtual Control Room for the Arctic) and FOLDOUT (Through-foliage detection, including in the outermost regions of the EU will develop and exploit PNT capabilities for maritime security and civil surveillance.

3.4.15 Multimodal travel user needs

GNSS is used by transport operators and on-demand service providers in various ways, starting from more efficient fleet management to accurate passenger information. **GNSS-based solutions can also allow for a further development of sustainable types of transport** by serving as a base for shared mobility, such as shared vehicles or free-floating bikes.

While the current use of GNSS in Public Transport is relatively limited in comparison to other sectors, an increasing number of public transport operators are using of Galileo-based applications in their day-to-day operations. This **growing trend to use GNSS-based solutions** is not limited to public transport, but also reflected in the ever-growing Mobility-as-a-Service solutions, as described in the EUSPA public transport user needs report. The use of GNSS is relevant for providing information to passengers on real-time locations of vehicles (public transport and on-demand) and delays in the schedule as requested by Commission Delegated Regulation (EU) 2017/1926 on multimodal travel information services (MMTIS).

Two main categories cover the increase of GNSS-based services:

- **Smart mobility**: efficient public transport requires increased performance for GNSS-based solutions. Within this context, multi-constellation multi-frequencies receivers will be able to improve the positioning in urban environment to meet the most demanding applications like collision avoidance, lane keeping, and automatic braking which will require authentication, integrity, and robustness. In addition, the increasing combination of several transport modes for the same journey requires real-time information on vehicles location and delays.
- **Safety critical applications** such as emergency breaking for trams or door control for trains may be enabled thanks to EGNSS signals and specific services (Galileo OS NMA, Galileo HAS).

3.4.16 Freight transport and logistics

The digital transformation of the freight transport and logistics sector, including the implementation of the Regulation on electronic freight transport information (EU 2020/1056) and the work of the Digital Transport and Logistics Forum focusing on the paperless transport and corridor freight information system, opens a possibility to develop a range of **new services for multimodal transport and logistics, including PNT technologies.**

Examples of the use of GNSS in this sector are:

- The **real-time tracking of containers** within the multimodal logistics chain and between logistics modes and actors is enabled by the real-time access to PNT information. This also allows to deploy real-time remote diagnostics monitoring systems.
- The use of PNT data connecting the **transport of dangerous goods** to the emergency services in case of accidents, providing the real-time location of the vehicle carrying dangerous goods and the exact content of its cargo.
- The improvement of **freight management services** by transportation stakeholders like rail service providers to become increasingly assets centred. Railway operators and infrastructure managers benefit from digitalisation because it improves **asset management** and maintenance, thereby reducing the operational costs. Those are recognised by the European Commission as a sustainable, smart, and safe means of freight transport with

GNSS receivers used to track rolling stock (more than 50 000 freight wagons of multiple EU railway undertakings are already equipped with GNSS-based telematic solutions).

Further information can be found in the EUSPA EO and GNSS Market Report 2022.

3.5 EU Cooperation on Satellite Navigation

The EU cooperate with several countries and international organisations on satellite navigation. This cooperation ranges from non-EU countries' participation in the EU Space Programme components to cooperation based on GNSS Cooperation Agreements.

In terms of participation to components of the EU Space Programme:

- **Norway** participates to Galileo, EGNOS and Copernicus via the mechanisms of the European Economic Area (EEA).
- **Iceland** participates to EGNOS and Copernicus via the European Economic Area (EEA).
- **Switzerland** participates to Galileo and EGNOS based on GNSS Cooperation Agreement signed in 2013.

In addition, the following **GNSS Cooperation Agreements** on GNSS exist:

- EU - **Norway** signed in 2009 covering security, export control and the protection of radio spectrum as well as of the Galileo and EGNOS stations on territory under Norwegian control.
- EU – **ASECNA** (Agency for Aerial Navigation Safety in Africa), signed on 2016, on the development of satellite navigation and the provision of associated services in the ASECNA's area of competence for the benefit of civil aviation. Under this Agreement the EU supports ASECNA in the development of a Satellite Based Augmentation System.
- The EU also concluded GNSS Cooperation Agreements with **South Korea** and **Morocco** covering spectrum protection, standards, trade, scientific and technical cooperation.

The European Union and its Member States have **privileged cooperation with the United States** in the field of satellite navigation since 2004, when the parties signed an agreement on the promotion, provision and use of Galileo and GPS satellite-based navigation systems and related applications. The cooperation aims to ensure that GPS and Galileo and Space-Based Augmentation Systems are interoperable at user level for the benefit of civil users. The cooperation also aims to maintain fair trade in the global satellite navigation market. The EU - US agreement was extended in 2022 by means of Council Decision (EU) 2022/1089.

The GPS-Galileo Agreement includes three working groups for cooperation:

- **WG-A Radio frequency compatibility and interoperability**: among other things, this WG ensures that Galileo and GPS are compatible at radio frequency level, in part through ITU Coordination, as well as aiming to make the respective civil signals interoperable as far as possible at system and receiver level. WG-A also helps to coordinate EU and US actions in other regulatory forums for the benefit of GNSS.
- **WG-B Trade and civil applications**: this WG aims to ensure that there are no regulatory barriers created by either side that would hamper the use of GPS or Galileo and their applications in respective markets.
- **WG-C Design and development of the next generation of systems**: this WG works on three streams of activities through three dedicated subgroups on:
    - Evolutions Sub-Group: it focuses the following areas:
        - R&D actions for the use of ARAIM in aviation and other domains and contribution to the preparation of ARAIM Standards for aviation.

    - Coordination of long-term R&D actions for GPS/WAAS and Galileo/EGNOS.
    - Coordination on next generation SBAS definition for user communities other than aviation.
  - Service provision Sub-Group: it focuses on aspects that are strategic for the provision of navigation services and exchanges on GNSS service provision aspects, status, and plans both for EGNOS/Galileo and WAAS/GPS.
  - Resiliency Sub-Group (RESSG): it focuses on the key topic of resilience of the GNSS systems against various types of threats. As part of this group, frameworks and standards used by ICAO and other bodies are developed. The purpose of RESSG is therefore to make GPS, Galileo, their augmentations, and their applications more resilient in the presence of harmful interference. The long-term objective is to develop solutions and propose recommendations that can be incorporated in future receivers, systems, and services.

The EU participates in the International Committee on Global Navigation Satellite Systems (ICG), established in 2005 through the U.N. Office of Outer Space Affairs. The ICG promotes cooperation on civil PNT and worldwide applications of satellite navigation technology. The ICG encourages coordination among GNSS providers, regional systems, and augmentations, to foster greater compatibility, interoperability, and transparency, and to promote the introduction and utilisation of these services and their future enhancements, including in developing countries.

The EU also works with Member States and other GNSS provider nations via the International Telecommunication Union (ITU) to ensure that radio spectrum, used for Galileo and other GNSS, is available and protected from interference, and that global rules governing radio use do not impact GNSS. This activity primarily takes place in ITU working parties (mainly ITU-R WP 4C) as well as at World Radiocommunication Conferences (WRCs), that take place every four years.

Finally, the EU works also on international satellite navigation issues through other multilateral bodies, including:

- International Civil Aviation Organization (ICAO)
- International Maritime Organization (IMO)

4 VISION for the EU PNT

The previous sections described the PNT ecosystem in the European Union, discussed the importance of Galileo and EGNOS across all markets and how new services are constantly introduced. They also highlighted limitations and possible threats to PNT services, as well as emerging PNT technologies, that address some of those concerns.

This section describes the (medium-term) vision for the EU PNT ecosystem. It is built considering the major trends of new constellations and signals, improvements in hardware and processing algorithms, increasing radio frequency interference and global connectivity.

From the **market segments** point of view, the tendency shown in the 2020 GNSS User Technology Report is mostly valid, where PNT services will be combined at user level in a sensor fusion approach to obtain the required performance:

- **Mass market** will use low-cost hardware but will demand more and more high-accuracy PNT services (cm-level), especially Galileo High Accuracy free service for intelligent transport systems, fusing GNSS services, augmented by PPP, sensor data and 5G. The use of multi-constellation, dual-frequency will be generalised.
- **Professional** will require multi-constellation, multi-frequency (e.g., triple) high-accuracy services fully integrated into a connected and automated workflow management. AI will be generalised and will revolutionise this market segment.
- **Safety-of-life and liability-critical**, traditionally constrained by regulations and standards, will adopt new technologies at a much slower pace. While important work is on-going to develop standardised multi-constellation, dual-frequency solutions, the real challenges will be to standardise resilient solutions, resistant to RFI. In addition, integrity to high-accuracy services will continue to be pursued for aviation (manned and unmanned) and autonomous vehicles and vessels.
- **Timing** importance will increase exponentially, being time synchronisation and distribution solutions vital for **critical infrastructure**, telecom, energy, finance, or transport sectors. Resilient timing will become a must and multi-frequency, multi-constellation, Timing-RAIM, interference monitoring and alternative-PNT services will be combined to complement GNSS.

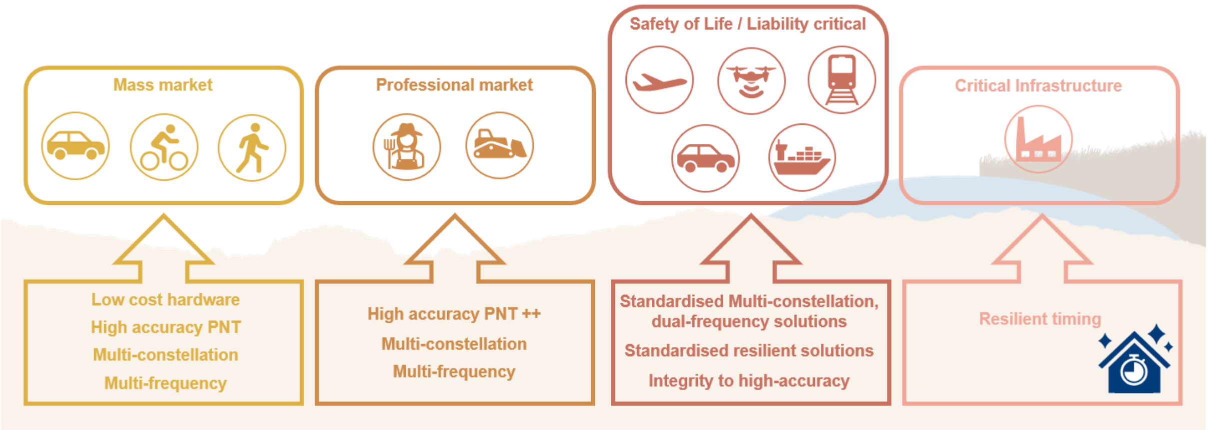


Figure 19 - Market Segments vision for the EU PNT

From the **PNT systems' architecture** point of view, the EU PNT ecosystem will become a System of PNT systems, with a combination of GNSS, conventional and emerging PNT services, all synchronised to UTC(k):

1. The **European GNSS** (Galileo and EGNOS) **together with GPS** will remain the **backbone of the PNT services in the EU**. The European GNSS services will be strengthened and improved with new services (high-accuracy, authentication, etc.), improved infrastructure (Galileo Second Generation, EGNOS Second Generation) and dedicated monitoring capability. The European Commission will continue pursuing the uptake of Galileo and EGNOS services with new Regulations, Standards, and the funding of projects for innovative applications.

   GNSS high-accuracy services such as the Galileo High Accuracy service, RTK or PPP will be **widely adopted** for high-precision applications.

   EGNSS-only solutions may also be required for specific applications and markets.

   Finally, the EU new proposed secure space connectivity IRIS[2] Satellite Constellation could also act as a platform for complementary PNT services, in addition to its primary communication mission.

2. **Emerging PNT** services, which can provide Alternative-PNT services, independent from GNSS, will **continue to develop** and more of them will achieve maturity and become commercially available, addressing the needs of the specific markets (e.g., indoors), or acting as a backup of GNSS services notably for the time provision to critical infrastructures. The EU recommends developing cross-sectorial Alternative-PNT solutions.

   On **timing**, the EU has the mature technology to provide highly accurate timing services independent from GNSS. The network of National Metrology Institutes (NMIs) will play a fundamental role in the time generation, while European companies offer commercial solutions for time distribution. The EU should work to fully develop the timing ecosystem and ensure cost-effective and resilient time provision to relevant users (e.g., critical infrastructures).

   On **position / navigation**, the market offers some commercial solutions independent from GNSS, however there are today no mature solutions from EU companies. The EU will work to support the implementation of the CER and NIS2 Directives (see section 3.4.1) and **improve** the **resilience** of the European economy and society. The EU should also consider the development of EU solutions to cover use cases requiring a strategic autonomy.

3. **Conventional PNT** systems, despite their disadvantages (e.g., cost, old signal, and hardware design) will remain in use for strongly regulated markets such as aviation and maritime and rationalisation plans will only be slowly implemented (also due to long lifetime of the equipment), while for non-regulated markets they are likely to disappear. However, some systems (such as the longwave time and frequency distributions) may maintain their importance as they offer good resilience to RFI although with limited performance (e.g., microsecond accuracy).

As a conclusion, due to the integral role of PNT in the well-functioning of the EU economy and society **RESILIENT PNT is paramount**. Underpinned by GNSS, PNT services need to be diverse and incorporate a holistic mix of technologies, terrestrial and space-based, since no single technology, even GNSS, will deliver sufficient resilience for critical users of PNT information. Resilient PNT will also require an efficient monitoring system, including for GNSS RFI and the necessary coordination procedures between GNSS providers, RFI agencies and governments:

The **EU PNT ecosystem** should become a **System of PNT systems** to achieve resilient PNT.

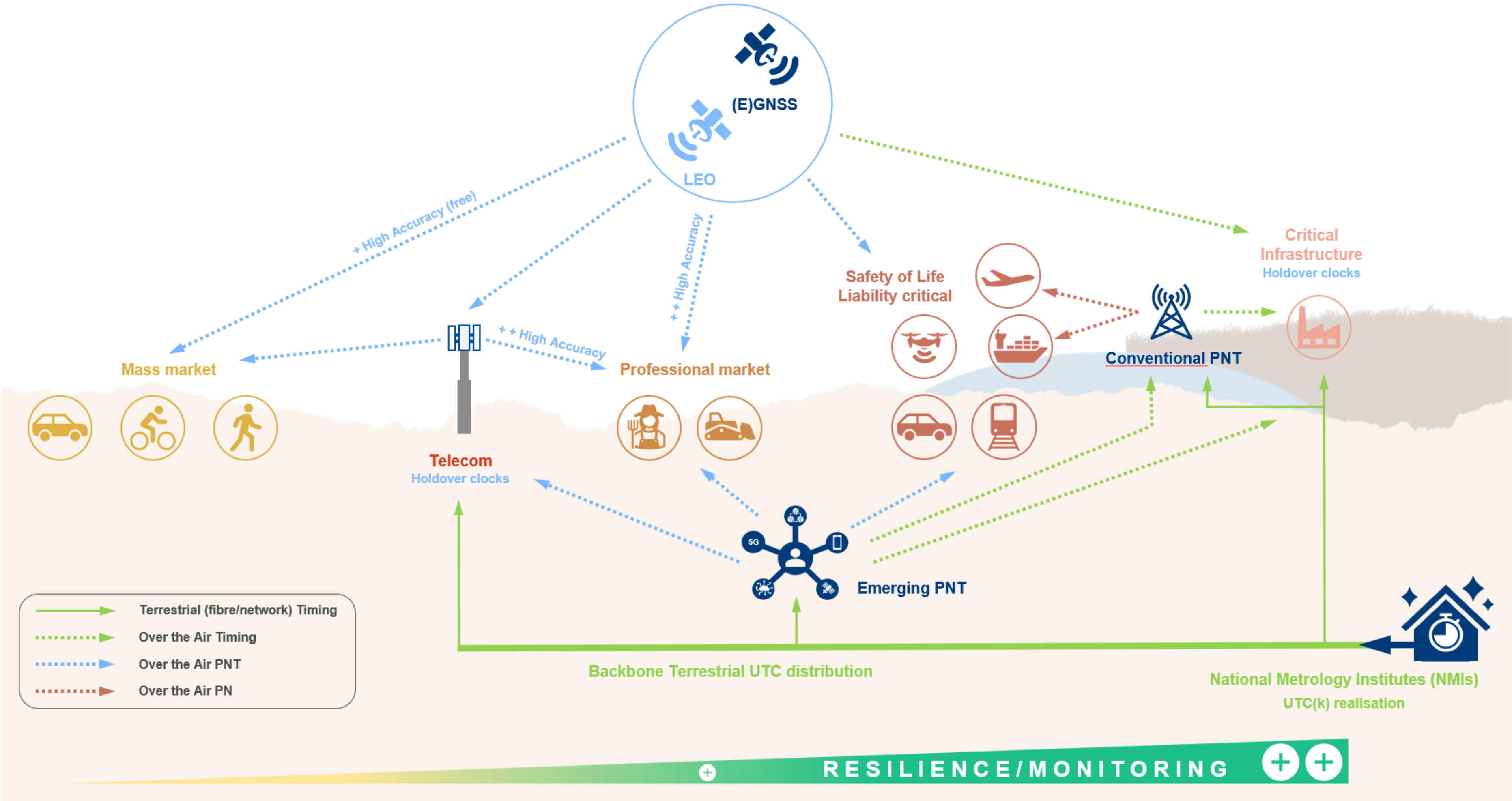


Figure 20 - Vision for the EU PNT