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European Radio Navigation Plan

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EXECUTIVE SUMMARY

This first edition of the European Radio Navigation Plan (ERNP) captures the characteristics of Europe's radio navigation landscape. It provides an inventory of existing and emerging radio navigation systems[1], foreseen modernisation plans, user requirements, a list of key stakeholders and an overview of the relevant EU legislation concerning radio navigation.

This initiative follows the European Commission's commitment to *"release a European radio navigation plan to facilitate the introduction of global navigation satellite system applications in sectoral policies"* in line with what was set out in the "Space Strategy for Europe"[2]. With this in mind, the overall objective of this ERNP is to inform policy-makers and stakeholders of the potential pathways for various sectors in Europe to take full advantage of Europe's GNSS[3]: Galileo and EGNOS[4].

More specifically, the publication of the European Radio Navigation Plan may contribute to:

- Allow for a coherent harmonisation of the suite of radio navigation systems available in Europe.
- Provide incentives to streamline investment in terrestrial Positioning, Navigation and Timing (PNT) infrastructure whilst improving the safety, robustness and security of the PNT landscape as a whole (for both space and terrestrial systems).
- Facilitate the eventual coordinated rationalisation of legacy radio navigation infrastructure across Europe.
- Support the definition of the optimal mix of radio navigation services matching the needs of key user segments (e.g., maritime, civil aviation, railways, autonomous vehicles, intelligent transport systems), enabling cost effective solutions that meet high standards with respect to safety, robustness and security.
- Reduce European dependency on non-European PNT systems.
- Provide a forward-looking perspective on the evolving ecosystem of radio navigation systems and infrastructures in Europe.
- Facilitate the adoption of the EU GNSS services and help define its modernisation plans.
- Establish synergies between sectors and facilitate the adoption of measures in one sector that were previously adopted in another.
- Support the definition of coherent European long-term strategies in key policy areas (e.g., transport, security and space).
- Support breakthroughs in Research and Innovation.

[1] "*Radio navigation systems*" are radio frequency systems used to determine the position of an object on land or in space. In some cases, they also provide precise timing for synchronisation applications.
[2] "Space Strategy for Europe", COM(2016) 705 final, October 2016.
[3] GNSS, Global Navigation Satellite Systems.
[4] EGNOS, European Geostationary Navigation Overlay System.

Scope of the ERNP

The process of optimizing the future radio navigation landscape in Europe is a collective endeavour that must be closely related to the needs of users, the quality of the services that are to be provided, the need for backup services, the level of investment required, etc. The ERNP offers an inclusive approach addressing the following user-segments or sectors relying on radio navigation services:

- Civil aviation
- Maritime and inland waterways navigation
- Road transport
- Agriculture
- Mapping and Surveying
- Location-Based Services
- Rail transport
- Space users
- Precise Timing and Synchronisation
- Emerging applications
- Security and Defence

This version of the ERNP addresses the radio navigation systems used in the above listed sectors: GNSS and their augmentations, NDBs, VORs, DMEs, ILS, MLS[5], Loran-C[6] and its evolutions, DCF77[7], mobile cellular networks and Satelles Time and Location[8].

Main Findings

Different sectors, including those that are heavily regulated, such as aviation and maritime, share a common understanding about radio navigation aids:

- The appearance of GNSS and their augmentation systems has caused a revolution for radio navigation. GNSS have become the dominant player in this field, allowing for operations in locations and in conditions that were not possible before. Examples include allowing near normal activity in low visibility environments, in bad weather and in heavy traffic situations.
- GNSS can deliver benefits to all sectors in Europe, facilitating routes that are new, more efficient, faster, more cost-effective, and that have a lower environmental impact. GNSS also allows for increased capacity and a more optimal use of transport networks.
- In the coming years, at least four GNSS systems will be operational (GPS, Galileo, GLONASS and BeiDou). All of them will have multi-frequency capabilities. Augmentation systems will

[5] NDB, VOR, DME, ILS and MLS are radio navigation systems of common use in the aviation sector.
[6] Loran-C is a radio navigation system that used to provide service to maritime users.
[7] DCF77 is a German time and frequency distribution system using low frequency radio waves.
[8] Satelles Time and Location is a private satellite navigation system, transmitting from Iridium satellites.

support the multi-constellation/multi-frequency environment. This will reinforce the performance of GNSS services for European end-users.

- For the aviation sector, because of the proliferation of GNSS and their augmentation systems, the rationalisation of classical radio navigation infrastructure like NDBs and VORs will be possible. In the maritime domain, Loran-C has already been switched off in Europe.
- The above developments lead to increased reliance on satellite navigation systems. GNSS now supports the overwhelming majority of user PNT equipment. With this in mind, it is paramount that every effort is taken to protect the GNSS signal frequency bands and to make it as robust and resilient as possible (by improving signal design, signal strength, antenna and receiver design, authentication features, use of space, time and frequency diversity, etc.).
- Galileo is already increasing the robustness and resilience of GNSS, providing a contribution to the multi-constellation reality (with more satellites in view at a given time and in difficult environments), operating on multiple frequencies (with better accuracy, better jamming resilience, better multipath resistance). Galileo will be the first GNSS system to provide authentication of the signal (making it more resilient against spoofing).
- In some specific cases, e.g. for critical applications requiring both continuous availability and fail safe operations, namely the critical phases of "Safety of Life" navigation, GNSS cannot be the sole means of PNT information. Contingency plans must be devised for such cases, resorting to redundancy, fault tolerance, recovery procedures, and/or independent back-up PNT solutions. Importantly, the additional technical means required to deliver adequate redundancy are often sector specific, and not necessarily radio-based.
- In this respect, the aviation community plans to keep an optimised network of DME (for performance-based navigation) complemented with ILS/MLS (for precision approach and landing) to provide basic navigation capabilities in the event of GNSS outage. A minimum operational network of VOR will also remain.
- The maritime community embraces the concept of "Integrated PNT System" consisting of an overlay of satellite based, shore-based and on-board components, to provide resilient PNT data during all phases of vessel navigation. In addition, studies are ongoing to test the feasibility of a back-up PNT system for GNSS using triangulating techniques based on signals from existing IALA[9] beacon station, AIS[10] base stations (both for the maritime and inland community) and Loran-C transmitters, or a subset of these.

Main Challenges

Despite the attractiveness of using GNSS in many sectors in Europe, there are still many challenges to address such as:

- All radio navigation signals are susceptible to natural and artificial interference, and GNSS signals being received at very low power are not exempt from these risks. To meet the present and future demands of users and for GNSS systems to overcome concerns related to liability and safety-of-life applications, GNSS services need to provide even more accuracy, increased availability and higher reliability. In addition, deliberate attacks on GNSS signals, like jamming and spoofing, are becoming increasingly sophisticated.

[9] IALA, International Association of Marine Aids to Navigation and Lighthouse Authorities.
[10] AIS, Automatic Identification System.

- The use of legacy infrastructure in specific sectors, like aviation, maritime and rail, and the associated cost of upgrading equipment for the users may limit the uptake of GNSS services.
- It is fundamental to ensure the interoperability between Galileo and other GNSS, and between Galileo and other positioning technologies, e.g. radar, lidar, sensors, 4G/5G, Wi-Fi that, in a near future, may become concurrent with GNSS in integrated multi-source terminals.
- Many applications in different sectors take place in very demanding scenarios for GNSS signals: tunnels, deep cuttings, urban canyons, indoor areas, locks, bridges etc. The characterization of GNSS signal propagation and performance in all of these environments is necessary.

This radio navigation plan shows the current state of play for radio navigation in Europe and provides the basis for continued analyses that can be used as input to overcome identified challenges; for determining the appropriate mix of systems that need to be retained and to decide what will be the priorities for future investment and divestment. Efforts must now focus on how Europe and the various sectors mentioned in this plan can optimise their PNT infrastructure in terms of finding the right system mix whilst considering the overall costs, the need to offset risk and the need to deliver continued high performance of PNT services to user communities.

1. INTRODUCTION

Background

Services dependent on radio navigation and timing systems have long since been an engine for economic growth. Radio navigation and timing systems also play a key role across multiple sectors in their support of critical infrastructures in the European Union. Whilst the dependency on radio navigation and timing systems is growing in civil and commercial applications, they are also playing an increasing role in defence, security and safety of life operations.

Both terrestrial and space-based radio navigation systems, otherwise known as Global Navigation Satellite Systems, GNSS, make up the landscape of radio navigation in Europe. For many years, terrestrial systems have played a key role in enhancing and strengthening Positioning, Navigation and Timing, PNT, services, either in combination with, or independently from GNSS. In recent years, 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 economy[11] relies on the use of GNSS systems, and the trends suggest that this is only going to increase. 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.

The uptake and evolution of GNSS solutions opens the possibility to decommission or rationalize some terrestrial-based radio navigation 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, like transport or critical infrastructure protection, it is broadly accepted that GNSS, even multiconstellation and multifrequency, should not be the unique source of PNT information. For those applications, a complementary, alternative or backup solution should be maintained or developed, not necessary based on radio technologies.

In light of the above, this Staff Working Document follows the European Commission's commitment to

> *"release a European radio navigation plan to facilitate the introduction of global navigation satellite system applications in sectoral policies"*

as envisaged in the Space Strategy for Europe[12] released in October 2016.

11 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

12 http://ec.europa.eu/docsroom/documents/19442

European Global Navigation Satellite Systems, EGNSS: Galileo and EGNOS

Galileo is Europe's autonomous GNSS under civil control, which offers state-of-the-art PNT services to users worldwide. EGNOS is a European augmentation system that improves existing navigation signals generated from the GPS. EGNOS offers better and more accurate signals for its users, adding integrity to critical safety-of-life applications, most notably in the aviation sector.

EGNSS offers continuous PNT services with global coverage. Through the diversity of their services, EGNSS provides:

- A real guarantee of service, including unabated availability and accuracy.
- The possibility to authenticate the data source.
- The integrity of the signal.
- The possibility to use an encrypted signal for highly sensitive security-related-applications.
- A High Accuracy Service, providing higher accuracy and integrity than the Open Service.

GNSS are currently being used to improve traffic flows and enhances vehicle efficiency. They help track parcels and shipments by providing added-value logistic solutions. They facilitate civil protection operations in harsh environments, speed up rescue operations and provide critical tools to coastguard and border control authorities. GNSS are also a formidable instrument for time-stamping financial transactions, and for conducting scientific research in areas like meteorology, atmospheric science, geophysics and geodesy, to mention a few. GNSS are also used for precision timing and synchronization, improving operational efficiency in critical economic activities.

Although the use of GNSS is increasing, the services offered by GNSS are not yet being fully exploited in sectors such as civil aviation, maritime and inland navigation, road transport, agriculture, mapping and surveying, location based services, railways, timing and synchronisation and in the emerging applications market. In the later, the use of autonomous, unmanned and remotely controlled vehicles is experiencing an exponential expansion in investment and use. Considering all, there is clear need for Europe to take full advantage of the benefits that Galileo and EGNOS can offer and to specify their impact sector by sector setting the basis for an ERNP.

2. PURPOSE OF THE ERNP

The purpose of this ERNP is to provide evidence to optimise the current radio navigation landscape in Europe in light of the growing importance of satellite navigation systems. In a modernised radio navigation systems mix, Galileo and EGNOS could play a primary role reaping the social, economic and environmental benefits that their use generates.

The main benefits would come from a reduction of the dependency on foreign space-based systems and a rationalisation of investments in the terrestrial infrastructures while improving safety, robustness and security of the radio navigation system as a whole (space and terrestrial). The ERNP is also a useful tool to highlight synergies between sectors and facilitate the adoption of measures previously adopted in other sectors.

More specifically, the European Radio Navigation Plan may contribute to:

- Allow a coherent harmonisation of the suite of radio navigation services available in Europe.
- Provide incentives to streamline investment in terrestrial Positioning, Navigation and Timing infrastructure whilst improving the safety, robustness and security of the PNT landscape as a whole (for both space and terrestrial systems).
- Facilitate a coordinated rationalisation of legacy radio navigation infrastructure across Europe.
- Support the definition of the optimal mix of radio navigation services matching the needs of key user segments (e.g., maritime, civil aviation, railways, autonomous vehicles, timing and synchronization, space users …), enabling cost effective solutions meeting high standards of safety, robustness and security.
- Reduce the dependency on foreign global positioning, navigation, and timing systems.
- Provide a forward-looking perspective on the evolving ecosystem of radio navigation infrastructures available in Europe.
- Support the definition of coherent EU long-term strategies in key policy areas (e.g., transport, security, space …)
- Facilitate the adoption of the EU GNSS services and help define its modernisation plans.
- Establish synergies between sectors and facilitate the adoption of measures in one sector that were previously adopted in another.
- Support breakthroughs in Research and Innovation.

Finally, this ERNP will allow the development of a framework of convergence to optimize the radio navigation landscape in Europe. It will be based on major '*guiding principles*', 'benefits', and 'challenges and *opportunities*' to optimize the radio navigation landscape.

The structure of this Staff Working Document

A Scoping Study on the Radio Navigation Services in Europe was produced to support this Staff Working Document. A workshop with Member States, held on 15 February 2017, did allow taking stock of key findings and gathering additional inputs on the Scoping Study to start the process of integrating the most relevant information and data into a single, coherent and integrated Plan.

The ERNP includes a comprehensive description of the status of the radio navigation systems, their expected evolution, the user requirements, the roles and responsibilities of the principal stakeholders involved in the design, management, and operation of radio navigation systems, and the relevant regulations in place.

The scope of this Plan encompasses terrestrial- and space-based radio navigation systems. The scope of the Plan does not include other systems and technologies used primarily for surveillance (e.g. radars, cameras …) or not based on radio frequency (magnetic sensors, lidar, inertial systems …). The systems addressed in this ERNP are the following:

- Global Positioning System, GPS.
- GLONASS.
- Galileo.
- BeiDou.
- European Geostationary Navigation Overlay System, EGNOS.
- Ground Based Augmentation System, GBAS.
- Differential GNSS, DGNSS.
- Non-Directional Beacon, NDB.
- VHF Omnidirectional Radio Range, VOR.
- Distance Measuring Equipment, DME.
- Instrument Landing System, ILS.
- Microwave Landing System, MLS.
- Loran-C / Chayka.
- Enhanced Loran, eLoran.
- Differential eLoran, eDLoran.
- Longwave time and frequency distribution systems, DCF77.
- Cellular networks based positioning.
- Iridium-Satelles Time and Location, STL.

For each of the radio navigation systems listed above, Annex 1 provides a description of the status with expected evolutions, the existing modernisation or rationalisation plans, and the exploitation strategies.

Annex 2 to this document provides a comprehensive description of the user requirements, the economic impact and forecasted growth of each particular sector of applications listed above. These elements are very relevant to understand how the mix of radio navigation systems is expected to evolve in the coming years.

Annex 3 presents a summary of the main stakeholders in the EU, representing the various user-segments and related associations, the providers of radio navigation services, the organisations in charge of the infrastructure deployment and operations, and finally, the EU Institutions in charge of developing the policy framework and managing the EU Satellite Navigation Programmes. The list of the identified stakeholders is the following:

- European Commission.
- European GNSS Agency.
- European Space Agency.
- European Defence Agency.
- Galileo service operator, Spaceopal.
- EGNOS service operator, European Satellite Services Provider.
- Eurocontrol.
- SESAR Joint Undertaking.
- European Aviation Safety Agency.
- European Maritime Safety Agency.
- European Fisheries Control Agency.
- European Union Agency for Railways.
- Shift2Rail Joint Undertaking.
- European Maritime Radionavigation Forum.
- International Maritime Organisation.
- International Association of Marine Aids to Navigation and Lighthouse Authorities.
- International Civil Aviation Organisation.
- Radio Technical Commission for Maritime Services

Annex 4 gives a summary of the main regulatory decisions taken regarding radio navigation services since 2010. It includes legislative procedures associated with key sectorial policies in the EU context, the management and promotion of the market-uptake of the EU GNSS Programmes through standardisation or international cooperation initiatives, the proposal of sectorial strategies and cross-sectorial policies such as the allocation of spectrum bands for radio navigation services in a harmonised manner.

3. THE RADIO NAVIGATION LANDSCAPE IN EUROPE

A detailed description of radio Navigation System can be found in ANNEX 1.

The availability of radio navigation systems in Europe is changing at a very fast pace, and will continue to do so in the short and medium term future. The last decades have seen the appearance and evolution of two global navigation satellite systems, GPS and GLONASS, together with ground and space-based augmentation systems. During the next years, we will see the start of operations of two new GNSSs, Galileo and BeiDou. A modernisation of these four global GNSS systems is also planned. Thus, in just a few years, there will be four satellite navigation systems providing global coverage with multi-frequency capabilities. Augmentation systems such as EGNOS will also evolve to become multi-constellation and multi-frequency. On the other hand, conventional ground-based aids to navigation will have the potential to be rationalised or even decommissioned. This will generate maintenance and operational costs saving. Their associated electromagnetic spectrum will be released and made available to other uses. For certain critical applications, like aviation, a backup navigation infrastructure will still be necessary to provide basic guidance capability in case of a GNSS malfunction or outage. Other critical systems, like the electricity grid or the banking sector, will need to assess their vulnerability to a GNSS outage, and their need for an alternative.

Figure 1 shows the expected evolution of the main radio navigation and timing systems available in Europe in the next ten years. We can make several important observations.

GNSS

At present, there are two GNSS systems with full operational capability (GPS and GLONASS), both providing dual frequency signals.

GPS has reached Full Operational Capability, FOC, in L1 and L2. There are 19 satellites transmitting in L2 C, and 12 satellites transmitting a third frequency in L5. The first launch of the new GPS Block III satellite, with an additional signal in L1 C, is scheduled for the second half of 2018. Depending on the pace of GPS launches, L2 C and L5 may reach FOC in 2020 and 2026, respectively. In that moment, GPS will become a triple frequency system. On that year, there will be approximately 12 satellites transmitting in L1 C. We expect the FOC of L1 C to start several years after, around 2030[13].

GLONASS has reached FOC in L1 F and L2 F. There are a few satellites transmitting in a third frequency, L3 C. A new generation GLONASS satellite will make its first launch in 2019, adding two new signals to the system, L1 C and L2 C. In 2022, L3 C will reach FOC, and GLONASS will become a triple frequency system. In 2025, L2 C will also reach FOC. We expect the FOC of L1 C to start some years later, around 2030 as in the case of GPS.

Galileo is currently in a deployment phase, with 22 satellites in orbit. The satellites transmit signals in three frequencies, E1, E5 and E6. The European Commission declared the Initial Services of Galileo on 15 December 2016. The development of the system will continue steadily in the following years, reaching FOC in 2020. Galileo will also evolve in the future, with the launch of a second generation

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13 GPS Update to PNT Advisory Board, 15 November 2017, Global Positioning Systems Directorate

of Galileo satellites. The Space Strategy for Europe calls for a stable evolution of the European Flagship space programmes including EGNSS. The evolution of Galileo is needed to continue delivering state-of-the-art services. In addition, future policy evolutions of Galileo may respond to new societal challenges and emerging needs.

The evolution of Galileo is also needed because of increasing competition, not only between GNSS systems themselves but also with other existing terrestrial systems (e.g. inertial sensors, ground-based beacons, eLoran, Wi-Fi ...) that offer alternative PNT solutions used in specific domains of applications. Today, several scenarios for the evolution of Galileo have been developed and will be analysed in the coming years.

The final decision on evolution should be made no later than 2020, once all aspects (architecture, technological choices, benefits and costs, available budget in next MFF) have been analysed in depth.

BeiDou, similarly to Galileo, is still in development phase. The satellites also transmit signals in three frequencies, B1, B2 and B3. The Chinese authorities plan to declare the FOC of BeiDou in 2020.

Year 2020 will mark an important milestone regarding the adoption of the GNSS services, when Galileo will reach FOC as a triple-frequency GNSS system. The availability of four operational GNSS will not only provide better availability and redundancy, but will also enhance RAIM (and ARAIM) techniques for better integrity. GLONASS and GPS are expected to also become triple frequency later on, in 2022 and 2026, respectively.

Following the evolution of GNSS, augmentation systems will also develop to augment the new signals available. In particular, **EGNOS** will evolve to augment both Galileo and GPS in the E1/L1 and E5/L5 frequency bands. At present, the deployed version of EGNOS is v2.4.1, and augments only the GPS L1 signal. With the planned deployment of EGNOS V3, the system will transform into a multi-constellation and multi-frequency augmentation system, to provide better service level, robustness and coverage. It is planned that EGNOS V3 will augment Galileo and GPS E1/L1 and E5/L5 signals in 2025.

The Air navigation case.

Beyond **SBAS** (and particularly **EGNOS V3**), providing enhanced Safety of Life services, **GBAS** will also evolve. At present, GBAS allows precision approach and landing Cat I operations using only the GPS L1 signal. It is planned that, in 2020, GBAS will allow precision approach and landing Cat II/III operations still using only GPS L1 signal. Several years later, in 2026, it is expected that GBAS will allow precision approach and landing Cat II/III operations using GPS L1 and L5 and Galileo E1 and E5 signals[14]. Multiconstellation and multifrequency GBAS will be able to provide the robustness required to support Cat II/III operations in low-latitude regions, which suffer from ionospheric anomalies. Furthermore, MC/MF GBAS will provide improved robustness levels in mid-latitude scenarios against full constellation or single frequency losses.

[14] European ATM Master Plan 2015

Having completed the full deployment of Galileo, EGNOS and GBAS, a rationalisation of other navigation aids infrastructure will be possible.

ILS is the most extended system for precision approach and landing, supporting Cat I/II/III operations. At present, Cat I operations are also possible using GBAS. EGNOS allows LPV 200 operations, which are equivalent to ILS Cat I. GBAS Cat II/III will enter into operations by 2020, which will permit the rationalisation of the ILS system.

NDBs and **VORs** are very old systems. After the declaration of the full operational capability of Galileo, expected for 2020, the Performance Based Navigation Implementing Regulation and the European ATM Master Plan propose to decommission the NDB network, as well as to reduce the number of VORs to a Minimum Operational Network. This network would provide some limited navigation capabilities in case of a loss of GNSS services.

An optimised or expanded **DME** network would also support performance-based navigation and constitute a backup infrastructure in case of GNSS loss. It is expected to begin the optimisation of conventional aids infrastructure network (VOR, NDB, DME, ILS) by 2020 ending up with a rationalised and GNSS-based performance-based navigation scenario by 2030.

The evolution plans described for the conventional aids to navigation (ILS, MLS, DME, VOR, and NDB) are those envisaged by ICAO, the international organisation that regulates civil aviation at global level and by the EU at European one. However, this infrastructure is ultimately responsibility of the different national authorities. These may have policies and plans that differ from those devised by international bodies, i.e., each member state in the European Union may have its own plan for rationalizing or decommissioning them. For example, France has published a national strategy to rationalise its ground equipment infrastructure by decommissioning VORs and NDBs, as well as ILS in order to transition to an ILS minimal network[15]. In Spain, a plan for the implementation of alternative flight procedures is in place with the objective of avoiding the dependency on a single navaid in each scenario. Most of these new alternatives are based on GNSS and once they are implemented, the rationalization or decommissioning of NDBs will be addressed in a case-by-case basis.

With respect to long-term reversionary solutions, the SESAR Joint Undertaking considers a multitude of new technologies that could be introduced to enhance or even replace DMEs and VORs. These Alternative Positioning, Navigation and Timing technologies, **A-PNT**, include Enhanced DME, Doppler VOR, Mosaic/DME, LDACS-NAV, eLoran, Wide Area Multilateration/TIS-B, pseudolites, Mode-N and inertial systems. According to the European ATM Master Plan, these A-PNT solutions are still under research, with the entry into service expected not before 2029.

Other cases.

The development of satellite navigation systems reduced strongly the number of **Loran-C** users. Following this, the United States, Canada and Europe have shut down and, in some cases, dismantled, most of their Loran-C transmitters. France, Norway, Denmark, and Germany terminated

[15] EU Air Navigation Strategy

their Loran-C transmissions on 2015. The GLA announced in December 2015 the discontinuation of its eLoran prototype service in the UK and Ireland[16]. Following France and Norway plans to stop their Loran transmissions, the GLA realised its eLoran service would not provide positioning and navigation capabilities to their users. eDLoran is a local augmentation system to eLoran. Since Loran-C and eLoran transmissions ceased in Europe in 2015, eDLoran services are not possible any more.

The GLA proposes a rationalisation of their radio beacon **DGNSS** service in 2021, following the full operational capability of Galileo.

The present contractual regulation of **DCF77** extends until 2021. However, we expect the service to continue after that date.

Cellular networks based positioning, currently **LTE** positioning in 4G networks, is available. The first 5G networks are expected to be available around 2020 in Europe.

STL started operations in 2016. Continuation of this service will depend on the owner's decision, which will probably be influenced by its commercial success.

The scenario described so far shows a clear tendency towards a greater use of GNSS systems and their augmentations. The advanced capabilities of satellite navigation systems make possible new applications and allow traditional operations in more demanding situations than before. Examples include operations under low visibility, close inshore and heavier traffic in already congested scenarios. This, in general, provides benefits and makes operations more cost-effective but, on the other hand, increases the vulnerability of the different sectors to an outage of GNSS. For critical applications, the principal stakeholders agree that having a single point of failure is an element of high risk that, as far as practically possible, has to be avoided.

Current and emerging applications will take advantage of the evolution of GNSS systems and their improved performances. At present, the aviation and the maritime communities rely on GPS, GLONASS and EGNOS in single frequency. In 2020, Galileo and BeiDou will reach FOC. The aviation and maritime sectors will immediately benefit from these new services. Also in 2020, the GSA expects the adoption of European GNSS in the railways traffic management system with its inclusion on the ERTMS. The adoption of augmentation systems, EGNOS and GBAS, with multi-frequency and multi-constellation capability is expected between 2025 and 2026.

Finally, there are several other sectors, most prominently the road transport, which are not as regulated as the aviation and the maritime ones. Those sectors will adopt the new services in a gradual form, as soon as they become available and there are products in the market that can make use of them.

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[16] https://www.nlb.org.uk/NoticeToMariners.aspx?id=1715

Dependency on GNSS and need for contingency measures.

Multiple sectors and services are adopting GNSS as the preferred technology for PNT. The strengths of GNSS are well known: high accuracy, worldwide availability, free of charge. However, GNSS signals are very weak, and vulnerable to interference, both natural or artificial, intentional or unintentional. GNSS users across different sectors are considering the effects that a GNSS outage could have. They are also establishing measures to prevent and react to those outages in case they happen.

All radio navigation systems, including GNSS, are vulnerable to jamming and spoofing. The availability of four interoperable GNSS constellations, together with improvements to SBAS services, will increase the difficulty of attempts to disrupt GNSS. Nevertheless, jamming incidents have been carried on with relatively low efforts and spoofing has been proven feasible with the adequate level of resources. Galileo OS Navigation Message Authentication will give additional means to detect anomalies in this sense.

There are certain environments where the usage of GNSS services is difficult or even impossible. Urban canyons are an example of the first, due to multipath effects and a reduction of the number of satellites in the line of sight. The availability of a greater number of navigation constellations will certainly improve this situation, since there will be more satellites within the field of view of the receivers. Tunnels, indoors or the underground are an example of the second. This gap in coverage is not acceptable for several users, like autonomous vehicles, and will need to be addressed.

At present, an alternative PNT system with global coverage and similar accuracy to GNSS does not exist. Instead, different sectors have their own initiatives according to their needs. The *aviation community* plans to keep an optimised network of DME (for performance-based navigation) complemented with ILS/MLS (for precision approach and landing) to provide basic navigation capabilities in case of a GNSS outage. A minimum operational network of VOR will also remain.

In the *maritime community*, some stakeholders are supportive of retaining Loran-C installations, and even upgrading them to eLoran. Despite this, several European national authorities decided to terminate Loran-C and eLoran transmissions on December 31st 2015. In the United States and Canada, Loran-C transmissions were also discontinued, although there is a renewed initiative to develop an alternative PNT system independent from GNSS. As a first approach, this backup could be limited only to timing information. One of the alternative backup systems under discussion is eLoran[17]. Studies are also ongoing to test the feasibility of the so called R-MODE, and if it is possible to make a back-up for GNSS using triangulating techniques based on signals from existing IALA beacon station, AIS base stations (in both maritime and inland waterway areas) and Loran-C transmitters, or a subset of these.

Other sectors are also looking for alternative PNT solutions that could serve as a backup for GNSS. There are many possibilities, which depend on the characteristics and the needs of the different users: radar, lidar, vision or acoustic based localisation, Wi-Fi, inertial sensors, magnetometers… The backup solution in general should offer resilience where the primary solutions manifest their weakness. For emerging sectors like autonomous driving and unmanned vehicles, accurate and resilient localisation and navigation capabilities will be fundamental.

[17] House of Representatives 2518, Section 411 Backup GPS, May 18th, 2017

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
GPS	L1	FOC										
	L1 C		<12 satellites								≥12 satellites	
	L2	FOC										
	L2 C	≥19 satellites			FOC							
	L5	≥12 satellites									FOC	
Glonass	L1 F	FOC										
	L1 C			<12 satellites				≥12 satellites				
	L2 F	FOC										
	L2 C			<12 satellites		≥12 satellites				FOC		
	L3 C	<12 satellites		≥12 satellites			FOC					
Galileo	E1	≥12 satellites			FOC							
	E5	≥12 satellites			FOC							
	E6	≥12 satellites			FOC							
BeiDou	B1	≥12 satellites			FOC							
	B2	≥12 satellites			FOC							
	B3	≥12 satellites			FOC							
EGNOS	GPS L1	FOC										
	GPS L5									FOC		
	Galileo E1									FOC		
	Galileo E5									FOC		
GBAS	Cat I (GPS L1)	FOC										
	Cat II/III (GPS L1)				FOC							
	Cat II/III (GPS-Galileo L1/E1 L5/E5)										FOC	
DGNSS		FOC				Rationalize						
ILS		FOC			Rationalize							
MLS		FOC			Rationalize							
DME		FOC		Optimize								
VOR		Rationalize			Minimum Operational Network							
NDB		Rationalize			Decommission							
A-PNT							Research phase					
Loran-C		Turned off										
eLoran		Turned off										
eDLoran		Turned off										
DCF77		FOC (Contract signed until 2021. Expected continuation after that date)										
LTE		FOC (4G). Initial operations in 5G expected for 2020 in Europe										
STL		Start of operations in 2016. Continuation of service will depend on company decision										

Figure 1 – Expected evolution of radio navigation systems in Europe

4. GUIDING PRINCIPLES

4.1 General guiding principles across all sectors

The market uptake of EGNSS and the process of optimizing and modernizing the future radio navigation landscape in Europe must be approached collectively and must be closely related to the needs of the users, the quality of the services that are to be provided, the need of back up services, the level of investment required etc. This holistic approach sets out guiding principles that must be followed throughout the decision-making / policy development process that will bring the ERNP to fruition. General guiding principles across sectors are presented below, without any order of priority:

- The development and evolution of the radio navigation landscape must be user-driven, and the performance of PNT services in terms of accuracy, availability, continuity, robustness and integrity shall meet the user needs.
- The radio navigation landscape shall evolve to get the best value for money and reduce costs, where possible.
- The radio navigation landscape shall evolve to adapt to the changing requirements of the users e.g. to meet the needs of emerging and new applications.

GNSS, and augmentation systems, have been a revolution in the domain of radio navigation systems. Furthermore, European GNSS Galileo and EGNOS provide a PNT solution that responds to the need of Strategic autonomy for Europe. GNSS are, and will remain for the foreseeable future, the dominant actor in this field.

GNSS, even multiconstellation and multifrequency, cannot provide the continuous availability of a fail-safe PNT required for the following critical applications:

- Existing applications:
  - Safety critical transport (aviation, maritime).
  - Critical infrastructures (power grids, banking system, telecommunication infrastructure).
- Emerging/future applications:
  - Safety critical transport (rail, road).
  - Unmanned vehicles.
  - Drones.

Different sectors may have similar needs for back-up or alternative PNT solutions. Identifying these cross-sectorial synergies is fundamental, as it would open an opportunity to share such solutions among the identified sectors, reducing the overall investments needed and making a cost-effective solution.

4.2 Guiding principles for the civil aviation sector

In 2004, the European Union adopted the Single European Sky, SES, legislative framework, which covered the provision of Air Navigation Services, ANS, the organisation and use of airspace and the interoperability of the European Air Traffic Management Network, EATMN. The SES legislative framework was supplemented by the extension of the competencies of the EASA and the establishment of a joint undertaking on R&D, the SESAR Joint Undertaking (SESAR standing for the Single European Sky ATM Research). The SESAR Joint Undertaking keeps up-to-date the European ATM Master Plan that outlines the essential operational and technology changes foreseen to deliver the SESAR contributions to the established SES performance objectives. The European ATM Master Plan is under update process based on the recent EU Air Navigation Strategy and Performance Based Navigation Implementing Regulation. Its section on Communications, Navigation and Surveillance, CNS, will be consistent with the ERNP.

The identified guiding principles for the civil aviation sector are presented below:

- The future of the CNS infrastructure will be based on the introduction of satellite-based technology (GNSS, SBAS, ABAS and GBAS) that enables key innovative applications that:
    - Improve the performance of the air traffic management (e.g. PBN-based air navigation procedures).
    - Increase airport capacity (ADS).
    - Improve the environmental and economic efficiency (e.g. lower noise impact, more efficient routes and fuel and emissions savings).
    - Guarantee safety.
- Special attention must be paid to potential GNSS failure modes and reversionary (back-up) modes of operation that are required to maintain a minimum level of service with an acceptable level of safety.
- The future air navigation infrastructure in Europe will make the best use of all available satellite technologies, including the use of EGNOS and Galileo services. In order to ensure the necessary independence when GNSS will be the primary means of navigation, Galileo and EGNOS, as systems owned by the EU, will become GNSS elements required in the EU within the multifrequency, multiconstellation GNSS system. Further legislative requirements could be foreseen for updating standardisation and certification of specific technologies and equipment and for ensuring that on-board equipment using satellite-positioning technology is compatible with the positioning services provided by the Galileo and EGNOS systems.

4.3 Guiding principles for the maritime and inland waterways navigation sector

IMO and IALA set out at global level the basic Required Navigation Performance parameters for a reliable component of the World Wide Radio Navigation System, WWRNS. Meeting the operational requirements in terms of accuracy, integrity, availability and continuity performance at system level, IMO recognized Galileo as a component of the WWRNS in May 2016. IMO stated in MSC 98 in June 2017 that SBAS/augmentation system does not require IMO recognition. IMO and IALA promote the e-Navigation concept based on robust PNT services with sufficient redundancy. A 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.

Proliferation of satellite-based systems at the global level, including augmentation systems and development of fast changing technologies (AIS, VDES, radars, racons) are setting the pace of the global regulatory framework evolution, making indispensable a planned coordinated approach between different national and international authorities.

EMSA statistics on incident and accident at sea recall the rising costs associated with collisions and groundings. Human error has a significant share in the overall amount. One cannot help but consider the role that GNSS evolutions can play in raising the level of maritime safety. An incremental approach to the evolution of the maritime CNS infrastructure might fill the gap between technology developments and regulatory framework resorting to immediate and long-term enablers along the following line:

- The future maritime navigation infrastructure shall make the best possible use of all available satellite technologies and shall be flexible enough to upgrade and incorporate new technologies. Safety at sea is associated with adequate radio navigation infrastructure that will be based on the introduction of satellite-based technology enabling key innovative navigation applications as well as on the flexible technological uptake of alternative non-satellite systems.
- Existing GNSS signal vulnerabilities are associated with local sources of error that need to be addressed both at system and at receiver level. Satellite-based radio navigation systems are vulnerable to outage, jamming and spoofing. All recognized GNSS components need augmentation systems to perform the most critical operations, i.e. navigation in harbour entrances, approaches and restricted waters. Nowadays, the most used augmentation system is IALA DGNSS.
- IALA DGNSS presents a limitation in areas where there is only one DGNSS reference station. By increasing the number of reference stations, DGNSS service reliability would increase. EGNOS can complement IALA DGNSS in most of the situations that need augmentation. It enables to fill possible gaps in the coverage area of the DGNSS service, providing a seamless augmented navigation solution, with lower installation and maintenance costs.
- A resilient radio navigation architecture has to take into account the future evolution of SBAS and of GNSS in general. Robust and resilient PNT information not only requires a core GNSS, an augmentation system and adequate backup. An integrity monitoring system is an essential element of any generic component of the WWRNS. Studies are also ongoing to test the feasibility of the so called R-MODE, and if it is possible to make a back-up for GNSS using triangulating techniques based on signals from existing IALA beacon station, AIS base stations and Loran-C transmitters, or a subset of these.
- SBAS could be encouraged through the development of standards specifically tailored for maritime transport. The objective is to make the best use of the SBAS performance compliance with the WWRNS operational requirements. Existing problems of interoperability and standardization are to be addressed within the maritime community.

The Common Fisheries Policy, CFP, is a set of rules for managing and conserving fish stocks, and establishing rules for European fishing vessels activity. Designed to manage a common resource, it gives all European fishing fleets equal access to EU waters and resources and allows fishermen to compete fairly. A range of technologies are used on a daily basis in order to monitor fishing activities and to support the enforcement of CFP rules, including rules on access to waters, fishing effort and technical measures control. The CFP relies on two major systems for vessel detection and activity monitoring which are sourcing data from PNT services. The Vessel Monitoring System, VMS, provides data to the fisheries authorities at regular intervals on the location, course and speed of vessels. The system is compulsory for EU vessels in all waters and for third country vessels in EU waters. The Automatic Identification System, AIS, is an autonomous and continuous vessel identification system used for safety and security of maritime and inland waterway areas. The AIS technology used in inland and maritime waterways is compatible. It allows vessels to electronically exchange with other nearby ships and provide authorities ashore with the vessel identification data, position, course and speed. AIS is mandatory for all vessels larger than 300 gt on international voyages or calling at a port of a member state of the EU. The carriage of an Inland AIS is mandatory on the river Rhine since 2014 and in some port areas. All EU fishing vessels above 15 m are required to carry AIS. Both VMS and AIS source the position, navigation and timing from PNT systems installed on board of the fishing vessels. A European PNT service with guaranteed availability and accuracy will have a direct impact on the validity of VMS and AIS for control purposes.

4.4 Guiding principles for the road transport sector

GNSS has been widely used in road transport since more than 20 years, in particular for turn-by-turn navigation. Initially mostly thanks to portable navigation devices, but also more and more through direct integration in the vehicle and/or smartphone applications. Moreover, thanks to the e-Call type-approval regulation adopted in 2015, all new models of personal cars and light duty vehicles in the EU must be equipped with GNSS compatible devices as from 31 March 2018.

Connected, cooperative and automated mobility aims at reducing road fatalities and congestion. To do so, future vehicles will increasingly exchange information, including their position, to coordinate manoeuvres and avoid accidents. To be effective, this will require more accurate and reliable PNT information. Additionally, automated vehicles obviously require accurate positioning independent of other road users. This is particularly important in extra-urban environments where natural reference points, such as buildings, may not be present to serve for relative positioning.

The mandatory uptake of regulated applications will bring communication and positioning platform on all vehicles, opening the way for new telematics applications:

- e-Call based on GNSS will become mandatory in all new cars and vans sold in Europe from 2018.
- Smart tachographs based on GNSS will become mandatory in all trucks sold in Europe from 2019.

Personal navigation devices are going out of the market, being replaced by integrated telematics devices and smartphones.

In-Vehicle Systems are growing due to more affordable prices and growing need for infotainment. This favours the uptake of innovative GNSS applications, following the increasing adoption of car operating systems such as CarPlay and Android Auto.

The need of increased accuracy and availability in urban areas characterises the positioning requirements of new MaaS (Mobility as a Service) applications and services leading to the adoption of multiconstellation receivers, and possibly multifrequency ones in the near future.

The need for the optimisation of the traffic management, the mitigation of pollution in urban areas and road safety by public authorities will further drive the adoption of PNT solutions.

4.5 Guiding principles for the agricultural sector

The market uptake of GNSS-enabled precision agriculture applications will increase along the need for increased food production caused by the rises in population, the intensified urbanisation and the adoption of western-lifestyle habits of developing countries.

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. This will lead to a further penetration of SBAS within agriculture GNSS receivers (currently at 80%).

High accuracy solutions (sub decimetres) for automation are commonly provided by RTK / Network RTK services, available all over continental Europe at very accessible costs. Real Time PPP services, either commercial or institutional (Galileo High Accuracy service) are being deployed and will complete the choice of services.

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. Within this context, whereas data collected comes from different equipment supplied by different hardware brands, interoperability and ease of use are key requirements of precision farmers.

The market uptake of multiconstellation receivers, enabling better performance and reliability of the positioning in GNSS-degraded environments, will further guide the adoption of GNSS in agriculture domain.

Accuracy will remain the most fundamental GNSS parameter for farmers. Reliability, availability, authenticity and coverage will also have relevance for specific applications.

4.6 Guiding principles for the mapping and surveying sector

Being the most accuracy demanding market domain, the main driving principle for adoption of GNSS will be the capability to offer increasingly better performances in terms of accuracy, availability, continuity and reliability, given the continuous demand for them by users.

The need for integrated solutions that make the best complementary usage of different technologies (including lidar and scanner), allowing for interoperability and software flexibility, will feed the demand for GNSS-enabled mapping and surveying equipment. GNSS receivers are integrated together with these technologies (also including total stations and photogrammetric cameras) to provide an absolute geo-reference to the local data acquired by those systems.

The landscape of Real Time Kinematic, RTK, applications is evolving with respects to:

- The proliferation of RTK GNSS receiver boards.
- The widespread availability of active and passive reference stations and RTK reference station networks operated by several national mapping agencies and commercial vendors.
- Significant decrease in the price of RTK GNSS receivers, due to a congested market and the competitive pressure from emerging Precise Point Positioning, PPP, solutions.

These elements drive the trend towards low-cost, dual-frequency (L1/E1 and L5/E5) receivers capable of cm-level horizontal and vertical precision. As these become widely available, they will enable the proliferation of RTK for a range of high accuracy applications.

Despite the challenges in delivering PPP solutions, particularly in a real-time environment, low cost dual frequency receivers are increasingly seen as a viable alternative to DGNSS solutions and are becoming popular amongst users who need sub-decimetre accuracy. This is especially true for users operating in environments where RTK is not an option (further from the coast), but also in areas where permanent networks are not available and the investment required for a full RTK system (two receivers + a datalink) has to be compared with the lower cost of a PPP solution (one receiver only). Thus, in the context of centimetre accuracy applications, while RTK remains the premium option and offers immediate solution convergence, the minimal equipment needs and global accessibility make PPP an interesting alternative, providing opportunities also for the Galileo High Accuracy Service.

4.7 Guiding principles for Location Based Services

Smartphones are the primary platform to access Location Based Services, LBS, followed by wearables and tracking devices. The growing and diversifying usage of applications, such as the integration of positioning information in augmented reality scenarios and context-aware applications, will continue to drive the growth in LBS. The PNT solution of a modern, medium to high-end typical smartphone consists on:

- Multiconstellation GNSS receiver, including GPS and GLONASS, and increasingly Galileo and BeiDou.

- Wi-Fi positioning.
- LTE positioning.
- Sensor suite, including barometer, accelerometer, gyroscope, proximity sensor, compass, …
- Front and rear cameras, that allow map matching with georeferenced images.
- Communications capability, including 3G, 4G, Bluetooth, NFC, Wi-Fi, …
- Embedded digital maps.
- State-of-the-art hardware and software, to process all data in real time.

The ultimate goal is to reach a situation where navigation and timing capabilities are available anywhere, anytime. To fulfil that objective, the only option is the hybridization of receivers, making use of all the data coming from GNSS, communication networks and stand-alone sensors, to offer the best PNT information possible to the end-user. Here all sensors work collaboratively, providing a seamless stream of PNT information, irrespective of user location (e.g. GNSS in open areas, LTE in high-density city centres and tunnels, Wi-Fi indoors, embedded sensors in electromagnetic degraded environments …).

The emergence of the smart cities concept will drive the adoption of GNSS-enabled LBS in urban environments in view of:

- The complementarity of GNSS with additional smart cities-enabling technologies.
- The enhanced performances in urban environment offered by the proliferation of multiconstellation receivers.
- The fact that GNSS still constitutes the most effective location technology in outdoor environments.

4.8 Guiding principles for the rail transport sector

The European Railway Traffic Management System, ERTMS, is a major industrial project aiming to replace Europe's different national train control and command systems with a single, coordinated solution. The deployment of ERTMS will enable the creation of a seamless European railway system with aligned signalling, essential to increasing the competitiveness of European railways.

Today, GNSS systems in the railway domain are predominantly used for non-safety related applications. Passenger information systems is the main application whereas GNSS is used, 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. These applications require a very high level of performance. Depending on the strategy towards them, GNSS may be used as:

- Primary means as foreseen in the US with PTC.
- A back-up solution as planned in Europe.
- One of the means within a hybrid solution.

The increasing demand for additional capacity of railway lines will foster the development and adoption of GNSS solutions. New solutions will need to be competitive, with minimum infrastructure and operational costs, which will also play a major role forming future demand for GNSS in rail applications.

4.9 Guiding principles for space users

Space missions are very complex. Spacecraft need to cope with very difficult tasks and, at the same time, have very stringent restrictions in terms of power, weight, size and volume. Consequently, space applications constitute a very demanding domain. The principal guiding principles for space users are the following:

- **Multiconstellation.** The availability of GNSS signals is very limited in certain orbits (e.g. GEO, GTO, and HEO). To maximise the number of signals visible in those orbits, and, consequently, the availability of the positioning service, it is fundamental the use of multiconstellation receivers.
- **Ultra-sensitive receivers.** Space users in orbits different from LEO need to use ultra-sensitive receivers. GNSS signals, at the Earth's surface, are very weak by design. At certain orbits, like GEO, the received signals are even fainter due to the combination of two factors:
    - Users located above the orbit of the GNSS constellations (e.g. GEO) need to rely on GNSS signals passing over the shoulder of the Earth and coming from the other side of the Earth. The increased distance implies a reduced power received.
    - On Earth's surface, signals received are those transmitted within the main lobe of the GNSS satellite navigation antenna. For GEO users, the signals need to pass over the shoulder of the Earth. For these angular regions, the GNSS satellite antenna provides less gain compared to the Earth field of view. The relevant angular regions include the edges of the antenna main lobe (for which some GNSS already have established specifications) or even the antenna side lobes (for which so far no GNSS has established specifications).
- **Cross-correlation isolation.** Signals received by space users from the different GNSS satellites may have very different power levels between them. Thus, it is fundamental that the navigation signals provide good cross-correlation isolation to allow for a reliable differentiation between all arriving signals despite the high power variation.

4.10 Guiding principles for precise timing and synchronisation services

GNSS provides precise timing and synchronization for most of the critical infrastructures: power grids, telecommunication networks and the financial sector. Power grids use GNSS timing in systems providing measurements relevant to the network status. Smart grid development is under way all over the world. Phasor Measurement Units, PMUs, are pivotal to the development of network automatic protection systems. PMUs are deployed across remote locations of the power network requiring a microsecond level of accuracy. Telecommunication networks use the GNSS timing function for handover between base stations in wireless communications, time slot management and event logging. The finance sector, i.e. banks and Stock Exchanges, uses GNSS to timestamp financial transactions, allowing tracing of causal relationships and synchronizing financial computer systems. The main applications are financial transaction timestamps.

Robustness and resilience in the timing and synchronization services are key to avoid serious consequences on the operation of telecommunication, energy and financial networks and therefore large societal costs. Moreover, infrastructures in Europe are highly interwoven. Increasing the resilience of the network cannot be achieved by an EU Member State acting alone. Improving EU independency is a strategic objective for critical infrastructures.

Telecommunication networks are continuously evolving towards higher capacity, increased transmission speeds and exploitation of higher frequencies, which require more accurate timing and synchronization services.

On the other hand, for power grids and the finance sector, the present accuracy of GNSS timing may be sufficient. However, the advent of new risks may require more secure and reliable timing and synchronization services.

4.11 Guiding principles for the emerging applications sector

Internet-of-Things.

Internet of Things, IoT, is an emerging technology meant to improve our lives and speed up the digitalisation of our industries and societies. In conjunction with technologies such as artificial intelligence and interactive technologies, the advent of IoT will open new terrestrial and space application prospects in relation to connectivity, navigation and positioning. Connected and automated cars, electronic medical devices, industrial automation control systems or smart grids are only some examples of products and services. IoT technologies will be used in the management of Smart Cities and Urban Infrastructures, initial applications such as Smart Street Lightning will evolve to more complex systems e.g. smart grids or smart water management (including clean, irrigation and grey waters). Navigation systems are used for remote control and maintenance.

In multimodal and real-time mobility systems, maps will be more and more enriched with real-time information from the user community, such as Google-Waze, CityMapper and Urban Engines. As cities become more complex, new ways of moving around appear on the scene, and journeys rely less and less on a single means of transport and increasingly on interdependent complementary networks. In addition, personal preferences will be considered e.g. reduction of greenhouse gas emissions.

In addressing disabilities and elderly people needs, one of the most beneficiary uses of navigation systems in smart cities will be to provide with practical mobility solutions for citizens with disabilities, e.g. for visually impaired persons or people with cognitive problems.

The deployment of Low Power Wide Area Networks, LPWAN, stimulate the Internet-of-Things, IoT, growth. The aim of LPWAN technology is to provide cost-effective connectivity to billions of IoT devices, supporting low power consumption, the use of low-cost devices, and provision of broad coverage. Most devices are mobile and restricted to battery power. As a result, low power consumption positioning technologies remain a priority.

Remotely Piloted Aircraft System and Drones.

The evolution of regulative aspects towards a less fragmented framework concerning matters under the responsibilities of single Member States (including the authorisation, certification and spatial limitations) will drive the uptake of RPAS technologies in Europe.

The majority of commercialized RPASs will be consumer-level products, with limited range and restricted flight capabilities. Relevant niche, however, will be composed by prosumer and commercial RPASs that will grow in number until exceeding other traditional aviation sub-segments very rapidly.

GNSS are a key enabler for the promising drone service market and the new EU and SESAR plans for a U-Space[18]. Air traffic insertion technologies, including surveillance or geo-fencing, and mission related functionalities, will rely on performing GNSS signals. Concrete requirements and features for air traffic insertion will be developed by SESAR and integrated into the ATM Master Plan.

The 4th industrial revolution.

The fourth industrial revolution will introduce the need for wireless positioning solutions in manufacturing and construction operations. Industrial robots, other mobile manufacturing devices and wearable devices for factory and construction workers will need positioning solutions that are reliable, safe, secure and highly accurate and function both in indoor and outdoor environments.

4.12 Guiding principles for the Security and Defence sector

PNT services are key enabling capabilities in security and defence operations. Space-based radio navigation signals (in particular the secure GPS P(Y)) are used as the primary source of PNT information for military forces. With the increasing reliance on GNSS within multiple military systems, the EU defence sector seeks to maintain the right level of PNT capability and autonomy especially in light of the evolving and increasing threats to PNT information assurance. Within this context, a European Military Satellite Navigation Policy to provide guidance to EU Member States for the identification of requirements for the military use of GNSS services was agreed in March 2017. Based on this Policy, a broader review of PNT capability requirements and priorities is being carried-out to produce a Common Staff Target document. Capability targets will be derived from the following principles:

- The performance of PNT services in terms of accuracy, continuity, and integrity shall be commensurate to operational needs defined by Member States in the Capability Development Plan.
- The delivery of PNT services must be under full European control or dependably provided by an allied defence partner.

[18] https://www.sesarju.eu/u-space-blueprint

- Due to the worldwide extent of the EU's area of strategic interests, PNT services must ensure global coverage. Therefore, EU Member States shall have the right to unlimited and uninterrupted access to secured PNT services worldwide.
- The PNT services for military use must ensure a high-degree of resilience against all threats and risks; this should explicitly include all aspects of cyber warfare.
- The highest levels of PNT service availability should be sought. PNT should be highly resistant to disruption, denial, deception, and degradation.
- The use of PNT services must be accessible in contested and congested environments.
- It must be possible to deny the exploitation of the secure PNT services by adversary forces.
- The interoperability of the PNT services must be ensured.
- The PNT services must be available with a high-level of reliability in all operational environments (in particular urban).
- Augmentation systems, regional or local, may be considered in order to enhance available services.
- PNT services shall be workable from strategic to tactical level, and from the most complex weapon systems down to dismounted soldiers' equipment.

Notwithstanding these principles, there is the need to coordinate future defence planning measures with other sectors, most notably the aviation sector.

5. BENEFITS AND OPPORTUNITIES OF USING EGNSS SECTOR BY SECTOR

5.1 General benefits and opportunities across sectors.

Galileo and EGNOS, together with BeiDou, and on top of the existing systems, GPS and Glonass, will form the basis of a multiconstellation and multifrequency environment. Besides, specific characteristics of Galileo, like authentication of the navigation message, will be crucial for professional and liability applications. Users across all sectors will benefit from increased accuracy, availability, robustness, security and safety.

Multiconstellation. The increased availability generated by multiconstellation is particularly important in urban and indoors environments. Although mobile cellular networks, Wi-Fi and related positioning techniques provide some help, GNSS remains the core positioning technology within such environments. This may be very relevant for sectors like road transport, LBS, timing and synchronization and Internet-of-Things. The integration of Galileo-embedded multiconstellation GNSS in RPASs is set to increase the accuracy and continuity of the received signals, thus directly contributing to an improved safety of navigation.

Multifrequency. The use of dual-frequency receivers will decrease the vulnerability risks of GNSS signals to jamming and spoofing. Dual-frequency is a key enabler of improved accuracy and integrity. Mass-market products, presently, only use the L1/E1 signals. However, the uptake of E5/L5 signals is expected in the coming years. Chipset manufacturers are already working to launch a new generation of GNSS receivers that exploit the more accurate and reliable positioning offered by dual-frequency signal processing. In this regard, Galileo L5/E5 has key features that make it a better option:

- The L5/E5 signals offer superior multipath mitigation and better accuracy than the L2 ones thanks to the use of a ten-time higher chipping rate (10.23MHz vs. 1MHz). This means the correlation triangle is ten times narrower in E5/L5 than in L2 (30m instead of 300m).
- The received power on L5/E5 is 3dB higher than on L2, a very significant advantage for use in constrained environments.
- L5 is an Aeronautical Radio Navigation Service frequency (as L1), thus better protected from in-band interference than L2.
- There will be many more satellites on L5 (All GNSS + IRNSS) than on L2.

Authentication. Thanks to the authentication feature, Galileo will counter the threat of intentional and malicious GNSS interferences like spoofing. Applications such as autonomous vehicles, road user charging, digital tachograph and insurance telematics will benefit from this feature. It will benefit those mapping and surveying applications whereas a legal value of the position is foreseen (e.g. cadastral ones). With the integration of payment systems in the smartphones, location information could be used as a key authentication factor, relating user location with purchase events and helping to reduce fraud. In the Internet-of-Things field, there is growing appreciation of the magnitude and breadth of the security threats. In some cases, devices require added protection because they may control mission critical equipment that generate sensitive information. In this context, Galileo authentication could be a valuable feature to increase the robustness of GNSS solutions against spoofing. Finally, RPAS users will soon be able to gain additional trust in the correctness of their position whilst being protected from malicious interferences.

Research and Innovation, R&I. GNSS also offers generous opportunities for academic research (*e.g.* geology, oceanography, meteorology and climatology, environmental sciences, astronomy). R&I programmes in GNSS greatly benefit universities and national research centres, fostering student mobility and international cooperation. European GNSS downstream industry and value chain has a huge development potential, already initiated through EU-funded R&I projects related to GNSS supported under FP7 and H2020 programmes. It is recalled that research and innovation activities carried out under both programmes have an exclusive focus on civil applications.

5.2 Benefits and opportunities of using EGNSS in civil aviation

Galileo and EGNOS may contribute significantly to the modernisation of aviation in Europe. The use of EGNSS in civil aviation offers plentiful advantages with respect to the conventional air navigation systems for all the involved aviation stakeholders.

Accessibility of small European airports. Increased accessibility of small regional airports, possibly remotely located, means highly improved connectivity. Connectivity is key in the modern globalised world and in a continent like Europe, often underperforming in terms of economic competitiveness. The opening of new routes and new connections has a huge positive economic and social impact. Linking different communities otherwise isolated brings social cohesion and development, it fosters business and trade and it boosts local economies. Currently, insufficient ground infrastructure of small regional airports prevents some companies from opening routes. EGNOS enabled LPV procedures allows landing without ground infrastructure. For a small regional airport, this means lower opportunity costs, considering that the airport operator is not compelled to costly investments to acquire and maintain an ILS. Supporting regional airports accessibility in all weather conditions will also help decongest major hubs.

Increased safety. EGNOS can provide a cost efficient and safer solution for non-precision runways. EGNOS enabled LPV procedures provide increased vertical accuracy, improving safety by reducing occurrence of controlled flight into terrain (by as much as 75%). They also enable the implementation of more flexible and safer approach procedures for rotorcrafts.

Search and Rescue. Rotorcraft operators, often operating in extreme weather conditions and in total absence of ground-based navigational aids, can also greatly benefit from the use of EGNSS. Whereas nowadays a considerable number of missions have to be aborted, in the future they could keep safely conducting their operations in all weather conditions saving more human lives. Unfortunately, only about 2% of aircraft are currently equipped with EGNOS avionics. Raising awareness of the EGNOS benefits and making EGNOS adoption by airspace users financially viable is of outmost importance for the uptake of this strategic technology for Europe.

Cost savings following rationalization of ground and airborne equipment. Galileo, EGNOS and GBAS provide an opportunity for rationalisation of traditional navigation infrastructure (e.g. ILS CAT I, NDB, VOR) reducing the costs for maintaining and operating the aging conventional systems. The counterpart airborne equipment can also be removed. Likewise, GNSS allows aircraft to broadcast their position using ADS-B, which will in turn allow air navigation service providers to rationalise their Secondary Surveillance Radars while increasing their surveillance capabilities.

The expansion of GNSS is expected to contribute to the implementation of the ICAO Performance-Based Navigation concept. The EGNOS Safety of Life service is widely recognized as one of the key enablers of Required Navigation Performance operations. The upcoming Commission Implementing Regulation on Airborne Collision Avoidance Systems and Performance Based Navigation is expected to boost the GNSS use in civil aviation in Europe.

Compared with US, GPS and WAAS create confidence in the market in general and especially in aviation. Authorities have approved approximately 4000 WAAS-based procedures for aircraft landing in US airports since the first Federal Radio Navigation Plan was published in 2001. This represents approximately 70 % of the airports WAAS could serve and reflects 10 more years of operations.

European GNSS Downstream industry and value chain. The GNSS market for civil aviation is already largely developed with promising figures for the years to come. The European GNSS Downstream Industry is already flourishing, creating direct and indirect jobs across the whole value chain (device manufacturers, aircraft manufacturers, airspace users, ANSPs and airport operators). The execution of EGNOS V3 evolution roadmap (fulfilment of the SBAS L1/L5 standard, expansion to dual-frequency and evolution toward a multiconstellation concept) is expected to bring additional momentum to the GNSS industry.

Environmental benefits. PBN allows for optimisation of horizontal and vertical profiles, which implies fuel savings and fewer emissions. In addition, in approach and departure segments, GBAS will allow creating noise abatement procedures such curved approaches.

5.3 Benefits and opportunities of using EGNSS in maritime and inland waterways navigation

The European maritime industry as well as Member States' surveillance and enforcement bodies strongly rely on GNSS and to a swelling degree on downstream services. Users want to navigate faster and at lower costs without compromising safety and security in a landscape where collision and grounding still represent a major issue. GNSS has become the primary means of obtaining PNT information at sea. Multi-constellation GNSS is the go-to solution for a wide range of maritime applications. For several years now, the maritime and inland waterways community has also used the EGNOS Open Service.

Ship operations. GNSS are used both for overseas, high traffic areas and to ensure safe navigation in inland waterways (rivers, canals, lakes and estuaries). Potentially, an EGNOS maritime service could provide another source of differential corrections and integrity information to complement the current IALA DGNSS infrastructure. It will especially enhance the approach and navigation in harbours and inland waterways. EGNOS differential corrections and local integrity checks can be received from geostationary satellites or, when using EDAS, via the Internet. In areas where EGNOS satellites may not be visible, such as shaded stretches of inland waterways and at high latitudes, EGNOS corrections received from EDAS can be re-transmitted using AIS base stations or by using other communication means. In the future, this re-transmission can also occur over VHF Data Exchange System, VDES.

Fisheries control. Fisheries inspection authorities use both VMS and AIS to deliver an integrated maritime picture. This maritime awareness has hugely improved the coordination and efficiency of inspection activities, providing for substantial savings in Member States operating costs. In addition, control services use PNT information to geo-reference observed fishing vessels and fishing activity against defined maritime and fishing area borders. Likewise, accurate and reliable PNT services will help the fishing industry to better comply with the rules of access to an area. Galileo signal authentication is expected to enhance the functioning of vessel monitoring systems to check the position of fishing vessels, as well as the time spent in international and foreign waters, protected marine areas, etc.

Port operations. Transit progress, docking and loading-unloading operations are monitored through GNSS-based technologies. EGNOS is operational and the number of users is growing. Work is ongoing to develop receiver implementation guidelines for EGNOS maritime receivers, and receivers that fulfil these guidelines. The background is to have EGNOS implemented in a similar way in all receivers to have optimal benefit from the system. Work is also ongoing to define a potential SoL service implementation in the upcoming EGNOS V3 system. This new service might also include a more mature integrity implementation for maritime than we have in EGNOS today. GNSS usage in ports is expected to grow rapidly due to increasing congestion in and around ports, combined with the ever-increasing size of vessels. In this scenario, EGNSS could support in particular two significant applications with even more stringent requirements than ship navigation:

- Portable Pilot Units. GNSS-enabled specialist navigation aids used to enter port.
- Port Automation, such as the tracking of shipping containers and other goods.

Multimodal logistics. The multimodal logistics industry has a strong need for reliability, security, flexibility and cost effectiveness. GNSS contributes to the monitoring of cargo along the entire supply chain and enables pivotal asset management applications. GNSS adoption for container tracking is growing, though barriers still exist. Equipping containers with GNSS-enabled telematics, shipping companies would be able to save on their insurance premiums.

Marine engineering. GNSS is used to support marine construction activities. Engineering and offshore subsea cable laying can be performed in shorter timeframe. GNSS plays an important role also in offshore oil and gas activities and seismic survey activities. The offshore energy industry uses augmentation systems and services (SBAS, DGNSS, PPP and RTK) that improve GNSS performance for various activities ranging from the initial surveying and offshore construction phase to drilling and the dynamic positioning of vessels near the platforms and construction sites. Working close to constructions and platforms often implies that only sectors of the sky are visible. Multiconstellation receivers (e.g. GPS and Galileo) would benefit from a higher number of satellites in view, increasing the availability of the navigation solution.

Search and Rescue. Galileo SAR service will help operators in a more efficient and effective way when responding to an emergency distress alert. It will also act as Europe’s contribution to the international COSPAS-SARSAT programme. The penetration of Galileo in Emergency Position Indicator Radio Beacon, EPIRBs, is expected to grow because Galileo will be able to provide a Return Link Service to inform the casualty of the reception of its message, becoming the only system to provide a two-way communication.

Unmanned, remotely piloted and autonomous vessels. GNSS is a key enabler for both traditional and innovative maritime applications and operations such as the use of drones and the development of smart ships. In the not so distant future, our seas and oceans might see the advent of smart and autonomous ships. It is expected that, in 20 years from now, ship intelligence driven by the smart use of Big Data will shape the maritime industry in general and the type of vessels in particular. Smart Ships will be able to support the crew in avoiding human errors. There are ongoing projects that are planning to have fully autonomous ships already by 2020, but specifications and development activities still need to be done. It is foreseen that standardisation will be a key issue in this application. As for cars, full autonomy is difficult to achieve, but we will see gradually implementations of features that will help the mariner to perform and gradually increase the safety, security and lower the cost of marine operations. Since autonomous shipping also implies a not negligible security risk, the use of the authentication service in Galileo is foreseen to be a key enabler for this evolving application.

IMO recognition. IMO recognised Galileo as a part of the World Wide Radio Navigation System. Galileo dual frequency receivers will be compliant with the accuracy levels required for navigation in ocean and coastal waters, harbour entrances and harbour approaches. This recognition represents a major milestone for the adoption of Galileo for use in commercial shipping and a boost for the current trend towards multi-constellation GNSS receivers.

Surveillance and environmental protection. Galileo, combined with SBAS, can be used to monitor and protect environmentally vulnerable areas, such as marine parks, and to monitor and prevent illegal fishing. Because of legislation under the EU CFP, some 9,000 fishing vessels in the European fleet are now fitted with GNSS-enabled vessel monitoring system devices, alongside mandatory AIS transponders.

5.4 Benefits and opportunities of using EGNSS in road transport

The road sector will benefit from the higher number of available satellites and from the redundancy provided by multi-constellation GNSS chips. Dual frequency (and especially the combination of E1/L1 and E5/L5) is the new development happening now in the sector, especially with the higher performances required by the first levels of automation approaching the market. For its modulation, E5 is considered more suitable to reduce local effects affecting navigation in urban environment, such as multipath errors. It will also benefit from anti-jamming and anti-spoofing measures, in order to ensure the reliability and continuity of the positioning service. In that sense, an authentication mechanism of the position service and some form of integrity leveraging also GNSS, but with more stringent requirements than for aviation, could reinforce the importance and usefulness of EGNSS for the road sector.

High Accuracy. Galileo will provide a High Accuracy Service based on the transmission of PPP information through its E6-B signal, delivering accuracy below two decimetres worldwide. Such service may bring additional benefits in the more demanding applications like autonomous vehicles.

Increased safety. EGNOS provides information on the reliability of the positioning information, allowing for greater safety in the transportation of dangerous goods across Europe.

New applications. Four Member States (Belgium, Germany, Hungary and Slovakia), as well as neighbouring Switzerland and Russia, have so far put in place electronic tolling systems for heavy-duty vehicles which make use of GNSS. More Member States consider implementing electronic tolling systems for heavy-duty vehicles using GNSS in the near future (notably Bulgaria). Tolling light vehicles (cars, vans) using the same technology is possible, although it is not considered for implementation in the nearest future because of the high cost of the necessary on-board equipment. This could however change in the middle-to-long term as the cost of the satellite positioning technology decreases.

Application-specific devices for the retrofit market. More and more vehicle models are fitted with a GNSS-enabled In-Vehicle System, which is set to become a platform to support both safety applications and infotainment services. This trend will bring both challenges and opportunities to aftermarket suppliers. Currently, only the latest vehicle models are equipped with built in applications such as insurance telematics, e-Call, ADAS and others. There is the possibility that the current scenario may favour aftermarket solution providers who could offer application-specific devices to a large retrofit market where EGNSS differentiators can play a key role.

Galileo value added for Mobility as a Service, MaaS. GNSS in general plays a key role within MaaS. On the one hand, it enables service providers to manage and optimise the use of the assets required to provide the different transport options. On the other hand, it enables the provision of smart mobility solutions to the users, including navigation, traffic information and journey planning directly. In the frame of MaaS, accuracy and availability in urban areas, as well as the need of trustable transactions, represent important requirements. Galileo is well positioned to satisfy those requirements, thanks to its additional satellites and to Open Service Navigation Message Authentication.

5.5 Benefits and opportunities of using EGNSS in agriculture

By increasing the accuracy, availability, reliability and continuity of satellite signals, EGNOS and Galileo can remove some of the barriers to the adoption of precision agriculture by farmers, in particular:

- Affordable and reliable SBAS solutions open up markets for entry-level users and pave the way for the adoption of more advanced solutions.
- The EGNOS Open Service improves the accuracy of GPS signals down to about one metre enabling operations like basic crop cultivation, fertilising and reaping, individual livestock positioning, virtual fencing land parcel identification, just to mention a few. In addition, EGNOS provides verification of the system's integrity, a feature necessary for any legal requirements farmers might have to meet, such as measuring fields for compensation under

the EU's Common Agricultural Policy. The same applies for CAP inspectors when carrying out on-the-spot checks to control the applications registered.

- Farmers can exploit the improved accuracy of EGNOS for Variable Rate Applications, VRA. VRA requires the use of GNSS sensors, aerial images, and other information management tools for determining optimum herbicide doses, fertiliser requirements and other inputs to help farmers save money, reduce their impact on the environment and increase crop yields. With VRA, farmers adjust their doses in field operations to the observed variability in the field. For example, only sections of a field with weeds are treated with an herbicide.
- The use of EGNSS real-time information allows applications for efficient tracking and tracing of the farm assets.
- The Galileo High Accuracy service will provide access to two additional robust signals, delivering higher data throughput rate and higher accuracy down to the decimetre level which will support more demanding precision agriculture applications such as high-value crop cultivation (e.g. potatoes and vegetables) or precision operations (e.g. sowing and transplanting). Currently these applications require the use of high precision services delivered via NRTK or emerging real time PPP techniques.

Emerging technologies in the agricultural domain represent promising opportunities for EGNSS adoption:

- RPAS. The utilisation of RPAS in precision agriculture marks an ongoing trend characterised by a number of dedicated R&D efforts, an increasing number of commercial solutions being launched and a strict regulatory framework constraining their uptake. RPAS are used either as an alternative to high-resolution imagery from satellites or as farming equipment (e.g. crop-sprayers). Their range of applications covers surveying flights in the planning stage of an agricultural project, yield mapping, crop-cutting records and field management. The utilisation of RPAS in precision agriculture represents an opportunity for EGNSS as key enabler of on-board autonomous navigation systems.
- Robotics. Another trend is the increased use of robots on a number of farming practices. Fully autonomous or robotic field machines are being increasingly employed in small-scale agriculture settings. Robotised precision farming promises to increase yields by optimising growth and harvesting processes while also helping to lower fertiliser and pesticide usage and improve soil quality through more targeted interventions. Automatic steering technologies and high-precision GNSS positioning enable the autonomous operations performed by robots. These applications currently require the use of NRTK or real time PPP techniques, and will soon be addressed by the Galileo High Accuracy Service.
- Crop insurance. The crop insurance industry can also benefit from positioning and Earth observation tools, as the technology creates better models to predict weather patterns and determine crop yields. With that information, crop insurance companies can set predictable rates and manage profits.

5.6 Benefits and opportunities of using EGNSS in Mapping and Surveying

EGNOS is contributing to the growing use of GNSS in real time mapping solutions by providing free metre-level accuracy available all over Europe. Thus, EGNOS eliminates the need for complex and costly equipment, including software solutions and the investment in the required infrastructure of augmentation service providers. For GIS and many mapping applications, the metre-level accuracy provided by EGNOS is sufficient. These applications include thematic mapping for small and medium municipalities, forestry and park management, and surveying utility infrastructures (e.g. electrical power lines). EGNSS enables simplification of the geo-referencing working methodology, cost-efficiency and the reduction of personnel needed to perform the work.

GNSS is the core technology at the heart of high-precision augmentation services offering cm-level positioning such as RTK and PPP, essential for surveying applications requiring high precision: cadastral, mining, infrastructure monitoring and construction. Galileo's Open Service offers either single (E1) or dual frequency (E1/E5), which further improve such augmentation services as RTK/DGNSS or PPP solutions. The resulting benefits for the surveying community, especially in multiconstellation environments, are many: mitigation of multipath errors, higher signal-to-noise ratio, increased availability, continuity and reliability, and better operation in harsh environments liker urban or natural canyons or under tree canopies.

In the future, Galileo High Accuracy Service will bring additional benefits:

- It will provide the first ever GNSS spreading code encryption for purely civil purposes, enhancing the robustness of the measurements.
- It will deliver corrections via Galileo E6 across the globe for decimetre-level positioning precision for applications across all segments, and it will be comparable to differential positioning techniques. Moreover, the High Accuracy service will offer triple frequency, enabling faster convergence time for surveying applications and accuracy comparable to RTK.

Democratisation of mapping GNSS devices. The reduction of GNSS receiver prices and the increase in the level of accuracy are transforming mapping into a more accessible activity. In particular, making accurate measurements easier to perform leads the market of positioning devices to the multiplication of integrated, highly performing and easy-to-use tools for an increasing range of positioning applications. Today GNSS receivers are more compact, reliable, highly performant and yet affordable thanks to modularisation. This trend is also prompting the collection of crowdsourcing data.

Crowdsourcing data. Simply using smartphones or any GNSS portable devices, combined with simultaneous localisation and mapping technologies, users become data collectors for mapping activities, especially in urban areas. This massive data collection is expected to change the paradigm of the mapping profession and is enhanced by the democratisation of GNSS mapping devices.

RPAS. Aerial and satellite images have been complementing mapping and surveying activities. Nowadays, RPAS can cut costs and time, streamlining the imaging process, ensuring flexibility and operators' safety in many activities: mapping; inspection of construction sites, mines and infrastructures; environmental monitoring and cultural heritage mapping. In addition to providing support to navigation systems, GNSS is widely used for geo-referencing collected imagery. In this context, the increased accuracy and authentication features of Galileo High Accuracy Service could become relevant.

5.7 Benefits and opportunities of using EGNSS in Location Based Services

GNSS is the main enabler of Location Based Services used for navigation, mapping and GIS, geo-marketing and advertising, safety and emergency, sports, augmented reality, games, eHealth, personal tracking and social networking.

Many existing applications benefit of an increased location accuracy such as location based advertising and augmented reality. Galileo, in combination with other GNSS, provides improved accuracy, availability and allows for a faster time-to-first-fix. Moreover, the strength of the Galileo signal, together with advanced code modulations, makes Galileo better for mitigating multipath effects, which are strong in urban environments.

Within emergency services, enhanced accuracy and availability offered by Galileo are at the service of authorities to localize distressed persons in the shortest time:

- E112 is a location-enhanced version of 112, the European emergency number, introduced within the EU 2002 Universal Service Directive. It requires cellular network operators to provide emergency services managers with the location information of the caller. Already employed in local architectures, it is expected that GNSS, and Galileo in particular, will be increasingly adopted.
- Galileo improved accuracy could also provide benefits in specialised smartphone applications for disaster management. The integration of crowdsourcing data from users, combined with other systems such as Copernicus and weather stations, will allow civil protection services and policymakers to effectively prevent and react during natural disasters.

Availability of pseudo ranges. Android operating system 7.0 allows access to GNSS raw measurements, giving more flexible and deeper access to positioning data. This data, previously inaccessible, opens up new possibilities for higher accuracy and deployment of algorithms currently restricted to more advanced GNSS receivers.

5.8 Benefits and opportunities of using EGNSS in rail transport

EGNSS will deliver integrity, improve availability and enhance accuracy for safety critical applications like railway signalling. Because of this shift towards a GNSS-based European Train Control System, ETCS, rail transport will benefit from improved safety and lower operational costs, offering safer rail journeys on regional and low-density lines, lower pollution, and more precise passenger information services. Current and potential benefits include:

- Real time, accurate and reliable train positioning with train identification can optimize real-time capacity allocation on the infrastructure.
- A solution for the fixed balise marker. Train positioning is currently based on balises, a physical element mounted at specific intervals along the railway track. The GNSS system can be used to provide the ETCS on-board system with a message equivalent to that provided to a fixed balise in the track for a position marker, enabling cost reductions while maintaining the operational safety of the ETCS.
- EGNOS can further support railway logistics applications such as the monitoring of freight and dangerous goods movement, offering a continuous tracking performance versus discrete performance of other currently used solutions based on alternative technologies. The next

version of EGNOS will augment Galileo signals, which may further enhance the service quality offered by EGNOS to the railway community. The effect can be magnified if coupled with train identification and a monitoring of the state and capacity of the network, leading to more reliable and available Expected Time of Arrival, directly linked with the specific goods transported.

- Galileo and EGNOS are actively contributing to the evolution of the ERTMS. By integrating EGNSS with additional sensors and public communication networks, the system is able to locate trains via satellite and monitor rail traffic.

5.9 Benefits and opportunities of using EGNSS for space users

Over the years, space users have become reliant on GNSS because the traditional infrastructures to support the localization of missions have been partly dismantled in favour of more efficient GNSS-based solutions. At the same time, new missions have emerged due to the possibilities offered by GNSS. For European space users, EGNSS means a reduced reliance on foreign GNSS systems and an improved performance when Galileo and EGNOS are used in conjunction with other GNSS. For the European space industry and satellite operators, EGNSS means the possibility to develop a capability not existing previously to support the implementation of the EGNSS programmes. The main benefits of EGNSS common for all space users include:

- Increased service availability, in particular at high altitudes, with the use of the interoperable Galileo signals with other GNSS systems.
- Significant improvement of real-time position, velocity and time computation.
- Support quick trajectory manoeuvre recovery.
- Improved spacecraft on-board autonomy.
- Increased operational robustness.
- Higher accuracy, in particular with the use of precise corrections form Galileo E6.
- Increased independence from other GNSS systems.

High accuracy corrections for precise orbit determination. Galileo is in a unique position to be the first system providing real-time precise corrections for GNSS orbit and clocks on a global basis through the high accuracy service foreseen in E6. This service will enable real-time centimetre-level position accuracy in space and would be very useful to support precise orbit determination at e.g. LEO altitude. Missions in Earth close proximity will benefit from resilience against ionospheric scintillation and availability over the Polar Regions. EGNOS transponders could also broadcast high accuracy corrections as additional signals on top of the standard SBAS broadcast.

The **CubeSat** community has grown exponentially in the last years. Operational missions are envisaged in the next future, and Galileo will be a key enabler to ensure position, velocity and time estimation in space.

Meteorological services already use radio occultation measurements. Galileo will improve the number of measurements and their quality.

Megaconstellations. The current plan for megaconstellations (e.g. OneWeb, Samsung, Google …) will rely on GNSS for positioning. Galileo could ensure availability and accuracy, which will open a huge market for Galileo space receiver manufacturers.

Galileo on the moon. Several studies show that the use of GNSS signals on the Moon is feasible and could support the development of permanent bases[19].

Implementation of European missions for the exploitation of GNSS reflectometry. The use of GNSS signals reflected from the Earth surface and received from LEO satellites has been proven in space (TechDemoSat-1). In December 2016, NASA launched a mission (CYGNSS) to exploit this technique for ocean wind speed measurements.

5.10 Benefits and opportunities of using EGNSS in precise timing and synchronisation services

Galileo, used as primary source of timing information or as redundancy solution, will improve the timing service availability, bringing another independent constellation to timing and synchronization operators. Galileo provides several key differentiators. In particular, Galileo authentication feature will provide resilience against spoofing.

The EGNOS time information can be obtained from GEO satellites or via the EDAS service, which allows users to access EGNOS data online in real time. EGNOS therefore offers a stable time service through two different channels.

There is an increased interest for Small Cells synchronisation. Small Cells are low-powered radio access nodes that operate in licensed and unlicensed spectrum that have a range between several meters up to 1 or 2 kilometres. Small Cell base stations can be deployed at street-level or within buildings and are key elements of the LTE and particularly in the 5G deployment. The Small Cells market is therefore growing very rapidly to support the need for greater coverage and increasing mobile broadband traffic. LTE Small Cells networks synchronisation can rely on GNSS. This is a potentially promising GNSS market as the outdoor Small Cells market is expected to grow by 43% CAGR from now until 2020.

Change in finance regulation. The new European Directive 2014/65/EU on markets in financial instruments (MiFID II Directive), was adopted in 2014 and will take effect from January 2018. To prepare its adoption, the European Securities and Markets Authority issued a Regulatory Technical Standards RTS25 on clock synchronisation. Article 4 of RTS25 states that *"Operators of trading venues and their members or participants shall establish a system of traceability to UTC"*. The traceability requirement implies to justify how UTC is generated, which means, for a financial operator, to be able to prove how the time stamp has been created. A built in-capability such as Galileo Open Service NMA could therefore be seen as an added value for this application.

[19] ESA General Study Programme, Weak GNSS signal navigation on the Moon, 2013-2015.

5.11 Benefits and opportunities of using EGNSS in emerging applications

Internet-of-Things.

GNSS for timing. Time synchronization allows IoT networks to impose order on streams of data from scattered sensors. This is the case, for instance, of the LoraWAN geolocation system. Although this service can be considered as a competitor for GNSS for positioning, it requires an extremely precise synchronization of base stations, which can be achieved with the GNSS timing.

Connected and automated driving, CAD. CAD is one the next big trends in automotive. It promises not only a more pleasant and comfortable mobility with passengers being able to do other things than focusing on driving, but it has also the potential to dramatically lower traffic congestion, casualty rates and reduce the environmental footprint. CAD comes also with a range of new digital services from navigation to culture, education or entertainment brought to the vehicle and representing a large reservoir of new high skilled jobs. Europe's leadership in sophisticated navigation systems is a big asset.

Remotely Piloted Aircraft System and Drones.

Integrity. EGNOS corrections provide end users in Europe with a free-of-charge means to improve the reliability and integrity of augmented signals. As these are enabling factors for urban area operations, they are expected to support EGNOS adoption. EGNOS also supports specialised applications such as geo-fencing. Generating substantial performance enhancements, it can effectively contribute to the integration of RPASs in non-segregated airspace

Need for better performances. The increasing pressure for better safety, reliability and jamming immunity will foster the uptake of dual frequency multiconstellation solutions, as in the case of conventional aviation. Addressing this need, the market can appreciate the improved capabilities of EGNSS. GNSS is the principal mean to achieve drone navigation for low-level flight, where more economic activity is expected.

The 4th industrial revolution.

Highly accurate positioning solutions will enable precise and flexible manufacturing and construction operations by autonomous mobile manufacturing devices, such as industrial robots. Also human-assisted manufacturing and construction operations will benefits by accurate positioning, in particular in outdoor situations such as, for example, assembly and maintenance of large offshore energy installations.

5.12 Benefits and opportunities of using EGNSS in Security and Defence

Military operations. EGNSS could increase the resilience, integrity and availability of PNT information and services within EU CSDP operations and other multinational and national operations. A stronger, secure and more accurate signal translates, amongst others, into improved weapons accuracy, logistics efficiency, surveillance and reconnaissance operations as well as command, control, communication and intelligence tasks. In particular, a higher weapons accuracy will allow reducing collateral damage during military operation. From this point of view, PNT services are crucial in order to improve the security of civil population.

EU strategic autonomy. The EU Global Strategy calls for the "autonomy and security of space-based services". To this end, an enhanced EGNSS would effectively reduce the EU's dependence on external systems and allow it to move towards strategic autonomy. This is especially important for crisis planning and conduct, and in light of the diversification of actors with access to space capabilities (BeiDou, Glonass …).

Increased/full-spectrum capabilities. EGNSS would enhance the capabilities available to the EU along all task lines (command, deployment, etc.) and create cross-domain synergies pointing towards full-spectrum capabilities. For instance, increased situational awareness would positively influence a multi-domain, multi-purpose operation. Furthermore, as stated in the European Military Navigation Policy, an EGNSS needs to be compatible with existing navigation systems in order to increase the spectrum capabilities of military systems.

Defence market. Innovations in the defence market can be furthermore enabled by the combination of the EGNSS services into novel robust PNT user equipment architectures to match with the specific defence operational and mission requirements.

European defence initiatives. The European Defence Fund, which supports industrial cooperation in defence, could help develop synergies between space and defence, if it is deemed a priority by Member States. Such solutions could also be developed in the framework of Permanent Structured Cooperation.

Civil-military synergies. Cross-sectorial common points could benefit both the civil and military domains. Jointly analysing and developing solutions for benefits such as information assurance (notably integrity and availability) or resilience, can prove not only cost-efficient, but would also ensure the introduction of integrated and integrative outputs at the EU-level.

6. CHALLENGES FOR AN OPTIMISED EU RADIO NAVIGATION LANDSCAPE

6.1 General challenges across sectors.

Better resilience of GNSS services. Intentional (e.g. spoofing, jamming) or unintentional (e.g. space weather, multipath) interference above defined levels may cause degradation and even loss of GNSS service. GNSS threats are multiple and the vulnerability to the existing threats represent an important challenge for users, receiver manufacturers, ANSPs and regulators.

In GNSS aeronautical applications, where high accuracy level and a precise evaluation of protection levels is of utmost importance, the elimination or reduction of ranging error is crucial. Corrective actions for multipath interference fortunately exist (narrow receiver correlator, carrier phase smoothing of code observations, etc.) and the use of Dual Frequency multiconstellation SBAS receivers or Advanced Receiver Autonomous Integrity Monitoring, ARAIM, is promising in this direction.

The possible use in the future of dual-frequency and multiconstellation receivers in aviation will offer the potential to reduce the risk of unintentional interference and increasing robustness against intentional interference.

In the maritime domain, GNSS positions can be manipulated before sending them to the control authorities. Availability of integrity check technologies (Doppler frequency checks) is therefore recommendable. The new authentication features of Galileo is foreseen to be a good tool to proof that the signals that are used for navigation has not been tampered with, and will make a big difference when it comes to critical applications.

For space users, ground RF interference visible from space is currently a major issue, in particular for radio occultation and GNSS reflectometry.

The timing and synchronization community is facing many challenges linked to an increased need for resilience, reliability and security. The frequency and severity of threats to GNSS systems is evolving from unstructured experiments to more organised attacks, better funded and prepared. The technology to disrupt GNSS has become much more accessible. With the advent of these new threats on GNSS and the increased importance of protecting critical infrastructures, resilience has become mandatory. Interactions with the user community have led to the identification of a need for future GNSS-based timing systems to provide a high level of resilience. Robustness and trust in the provided service is perceived as a higher priority given that the level of achievable accuracy is more than sufficient for the majority of the current timing applications.

Coverage. EGNOS only covers European and adjacent waters. However, the European Union's responsibilities concerning monitoring certain fishing activities and the fight against illegal, unreported and unregulated fishing go far beyond the waters of the European Union.

EGNOS LPV-200 availability in some geographical regions (Northern parts of Finland, Sweden and Norway, Atlantic Portuguese and Spanish archipelagos, Eastern parts of Bulgaria and Romania) and in periods of intense solar activities can become a challenge directly affecting safety and the level of acceptance by the airspace users' community and certain Member States. System outages, often due to interruptions in the service of the primary satellite constellation, have also many consequences on the general perception of the system reliability. In the future, multi-constellation GNSS will allow the receiver to track more satellites and from different independent constellations, increasing the resilience of the system and decreasing the likelihood of service disruption.

For the space sector, GNSS signal coverage above LEO is also important. GEO, GTO and HEO orbits suffer the lack of continuous visibility of GNSS satellites. In addition, GNSS satellites are designed for optimal signal reception on the Earth surface. Consequently, space users at altitudes above GNSS orbits need to cope with significant lower received power levels. L5/E5a bands have a clear advantage over GPS L1 (improved signal visibility at high altitude, improved cross-correlation protection …).

Design and development of Galileo E6 receivers. Galileo is the only GNSS using the E6 frequency, and receiver manufacturers will likely be willing to invest primarily in quad-constellation receivers rather than on Galileo CS specific developments. A limited availability of CS capable receivers would be detrimental to the uptake of these services.

6.2 Challenges of using EGNSS in Civil aviation

Cost of airborne equipment upgrade. EGNOS-enabled GNSS receivers can represent a significant investment and the needs and the financial resources of the different categories of airspace users are quite diverse. The availability of published LPV procedures in the target airports has a significant impact on the decision of the operator to invest or not in the equipment. Business Aviation and Regional Aviation are the two natural candidates to be the champions of EGNOS adoption, due to the high use they make of regional and secondary airports, where LPV-200 procedures represent a valid alternative to ILS CAT I approaches. The challenge is to reach a critical mass of runway ends where LPV procedures are implemented, so to trigger the decision of airspace users to equip and achieve the vision of having SBAS fully used for final approaches. High retrofit costs for legacy aircraft can also be a problem; having to equip an entire existing fleet with EGNOS-enabled SBAS antennas and receivers can be a financial burden which regulators need to take into account in their activities. On the other hand, financial incentives can be quite effective in spurring investments.

Safety regulatory requirements. Civil aviation is a heavily regulated sector, this representing both a challenge and an opportunity for the GNSS use. Mostly safety-driven, civil aviation standards and regulations are very clear in terms of system performance requirements as specified by ICAO. Accuracy, integrity, continuity availability and robustness of the Signal in Space are all high priority key performance parameters for aviation, and the regulatory bodies are unsurprisingly very inflexible in this regard. Unfortunately, innovation is usually faster than regulation, and lengthy regulatory processes together with high certification costs make up a constraint for the GNSS system designers and manufacturers.

6.3 Challenges of using EGNSS in Maritime and inland waterways navigation

Choice of the components for a maritime resilient PNT. For the provision of resilient PNT, terrestrial radio signals as well as shipborne components are necessary in addition to GNSS. Some consider eLoran the ideal back up to GNSS and promote it at the IMO. However, the choice is challenged by the lack of international agreement and by high costs for reactivation and maintenance of cumbersome infrastructures. R-Mode is also a promising technological approach that will be tested out further in near future.

DGNSS infrastructure improvement. Maintaining and improving the IALA DGNSS service reliability by increasing the number of reference stations to enlarge the area where the user can receive differential corrections implies significant investment and maintenance cost. Potential SBAS based solutions applied over Aids to Navigation (DGNSS and AIS signals) as described in the IALA Guideline G1129 (Edition 1.0 Dec.2017) could provide some room for the rationalization of the infrastructure and address the current limitations of legacy DGNSS systems paving the way to the uptake EGNOS services.

Limited uptake of SBAS-enabled shipborne receivers. There is no maritime standard or guidelines for the implementation of SBAS in shipborne receivers and the majority of these implementations do not take into account the information related to the system integrity messages that the SBAS system broadcasts. Work is ongoing to develop receiver implementation guidelines for EGNOS maritime receivers in RTCM, and receivers that fulfil these guidelines. The background is to have EGNOS implemented in a similar way in all receivers to have optimal benefit from the system. The challenge is to ensure an appropriate integration of SBAS in shipborne receivers that would contribute to improve the accuracy and the reliability of the positioning information, which at the end is one of the main factors to guarantee the safety of life at sea. Work is also ongoing to define a potential maritime SoL service implementation in the upcoming EGNOS v3 system. This new service might also include a more mature integrity implementation than we have in EGNOS today.

Inland waterways. 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 have been established to some extent also to cover the inland waterways. In addition to this, distribution of DGPS data is also done in some 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 shadowing and blocking of satellites due to land shadowing, mountains or obstructions from man-made objects. The inland navigators would therefore benefit from multiconstellation navigation, because more satellites are available. There are also reasons to believe that these users could benefit from the High Accuracy Service from Galileo and future dedicated EGNOS V3 services for maritime use.

Number of installed GNSS devices. Although AIS is only mandatory for fishing vessels of 15 m LOA and above, smaller fleet segments are increasingly installing AIS on-board. The management, integration and operational use of such large amounts of PNT information pose a challenge, in particular when such information is integrated in a common maritime picture.

Adoption of GNSS in multimodal logistics. Despite the benefits available to multimodal logistics players thanks to GNSS monitoring of containers, its adoption is still limited. Key reasons include operational costs, power consumption when monitoring unpowered assets, durability issues of the devices subject to harsh environment during the carriage and signal availability when containers are stored in lower decks of vessels or in warehouses. Once these challenges are solved, the industry foresees a steady growth of GNSS adoption, assisted also by decreases in equipment costs via economies of scale.

Identification of vessels using GNSS services. The obligation for fishing vessels to carry AIS and the possibility for Member States to use AIS for control purposes are an important asset for fisheries monitoring control and surveillance. Although the accuracy of the received PNT information is very important, identifying the vessels providing the PNT information is often a bigger challenge. Steering the fishing industry towards the use of complete and standardised vessel identifiers when programming and setting up GNSS devices is of paramount importance.

6.4 Challenges of using EGNSS in road transport

Development of safety critical E-GNSS engine. In the near future, an architectural convergence is expected among In-Vehicle Systems that will need more reliable and accurate positioning to serve innovative applications. The current approach is to use different sources of information, including expensive radar based sensors, infrastructure-based sensors, differential techniques, etc. As previously proven by some R&D projects, European GNSS and its differentiators (e.g. the signal characteristics, services such as authentication, integrity service, etc.) can be essential to provide the needed accurate positioning. However, it is necessary to design a dedicated reliable and accurate engine, instead of simply adapting one from already existing, non-automotive specific consumer applications.

Foster adoption of more performant GNSS chipsets. The automotive industry commonly considers GNSS as a commodity. Traditionally, this industry has only taken into consideration basic GNSS performances. There are many technological innovations that can be better exploited by the automotive industry to improve safety and reliability, and some recent developments (e.g. the first dual frequency chipsets that are appearing in the market) confirm an emerging innovation trend:

- Multifrequency receivers for multipath rejection and increased availability.
- High integrity solutions tailored for the road environments
- Galileo authentication increasing robustness against external vulnerabilities.
- PPP and other High accuracy services

6.5 Challenges of using EGNSS in Agriculture

Limitations are primarily linked to constraints related to the environment in which agricultural operations are carried out (tree canopy, buildings or highly reflective surfaces) that can reduce GNSS signal availability.

Existing RTK solutions already offer high-level precision (~1 cm) for this industry. EGNOS and Galileo can provide only marginal improvement to crop management. However, EGNSS will progressively be included as it will represent a marketing opportunity for system integrators to add another feature and differentiate their solution.

6.6 Challenges of using EGNSS in Mapping and Surveying

Interoperability. Compatibility, concerning in particular interfaces and communication links, may enhance the uptake of innovative surveying techniques and expand it to new segments of application. The need of interoperability also among devices provided by different manufacturers is of key importance. Now, many different DGNSS/RTK data formats are available (e.g. RTCM, CMR, etc.), making the use of data coming from different sources and devices quite challenging. Typically, different brands have different levels of interoperability when it comes to receiving augmentation corrections from networks operating with equipment from other players considered as competitors. In addition, the integration of GNSS with complementary technologies such as lidar, laser scanners, remote sensing, MEMS, robotics, etc. is increasingly spreading. To obtain sophisticated integrated solutions, the setting of a common standard may be beneficial.

6.7 Challenges of using EGNSS in Location Based Services

Dynamic market. The LBS market is driven by the shortest lifecycle in the GNSS industry, which favours innovation but also brings important constraints on cost. The complexity of the semiconductors used in mobile applications has increased dramatically. Mobile chipsets are no longer just radio transceivers for call management; they now integrate also sensors and other RF technologies (GNSS, Wi-Fi, NFC, Bluetooth …). Beyond technology innovation, chipset manufacturers are focused on continuous improvements in costs, power consumption and performance, which have a direct impact on GNSS receivers adopted.

Battery life. Most of LBS devices are battery-powered, and must remain small and lightweight. Today GNSS is a relevant source of battery drainage for smartphones batteries. To keep pace of evolving requirements, efforts are needed in the development of new GNSS chipsets focusing on miniaturization of devices and reduction of power consumption.

Ubiquitous positioning. Increasing demand for ubiquitous positioning aims at closing the gap between outdoor and indoor LBS. It is important the continuity of the positioning, especially in urban canyons and at the doorstep. The challenge is to develop new positioning systems able to ensure ubiquitous positioning combining GNSS with complementary technologies (3G/4G, Wi-Fi, MEMS, 3D Mapping, SOOP ...).

6.8 Challenges of using EGNSS in Rail transport

Legacy systems. The solutions currently deployed make use of legacy technologies (e.g. physical balise, barcodes, RFID) that still represent an efficient and cost effective solution for the current safety and non-safety relevant applications. Where possible, the European rail community aims to replace the physical balises with virtual ones, based on precise GNSS-based positioning, while maintaining the operational safety of the ETCS.

Safety relevant applications. Within the rail domain, the market focus has mostly been on non-safety related applications, such as passenger information systems and freight logistics, which are typically not standardised. For these applications, according to the current knowledge, the GNSS performance in the railway environment is largely sufficient. Moving into the domain of safety-relevant applications, such as signalling and train control, a much better understanding of GNSS performance is needed. This is especially true for the future possible use of GNSS in ERTMS, where performances of GNSS receivers have to be harmonised in order to achieve a guaranteed performance in line with the relevant technical specifications for interoperability, which are currently based on non-GNSS technologies.

Rail environment characterization. Rail environment is very complicated in terms of GNSS signal propagation (tunnels, deep cuttings, multipath). The necessary level of knowledge regarding the characterisation of the satellite-based positioning performance within the rail environment is still missing and represents an important step towards the adoption of EGNSS in safety-relevant railway applications. R&D actions are required to predict the performances of GNSS in the railway environment in regards to accuracy, availability and safety. The results will allow achieving interoperability between equipment of different suppliers, a key element that has led to significant applications of ERTMS also outside Europe.

6.9 Challenges of using EGNSS for Space Users

Designing and developing Galileo E6 for space users: space GNSS receivers using Galileo E6 do not currently exist.

Antenna side-lobe characterization. The use of antenna side-lobes significantly improve PNT performance. Commitments on GPS and the characterisation established for existing Galileo satellites only cover the navigation antenna main-lobe region, and side-lobe signal performance is not formally recognised. The characterisation of the antenna side-lobes and the publication of the resulting gain patterns is considered very beneficial for space applications.

6.10 Challenges of using EGNSS in Precise Timing and Synchronisation services

Development of standardisation initiatives to support EGNSS adoption. Presently there are not standards for GNSS timing and synchronization critical infrastructure applications. The challenge is therefore to engage key players in the European standardisation domain towards the development of standards for timing and synchronization services based on GNSS.

Better synchronisation accuracy. The fifth generation of mobile technology (5G) will be rolled out from 2020 implying an increase in traffic density. To tackle this need, spectrum efficiency should be significantly enhanced compared to 4G, so that operators will be able to sustain such huge traffic demands under spectrum constraints. The developments towards next generation communication networks standardisation and spectrum needs are under way in the 3G PP and ITU. The next World Radio Conference will be held in 2019 and concerns new spectrum to be used by vertical sectors so that they can benefit from Europe´s 5G strategy as outlined in the EC Communication on the connectivity for a European Gigabit society and the EC Action Plan on 5G. This includes the expected benefit of a common ecosystem for a wide range of vertical sectors like e.g. transport, eHealth, energy management, and possible safety applications.

In 5G, it is foreseen that the synchronisation accuracy will be improved by one order of magnitude compared with current actual values.

Digital Video Broadcasting will also require a significantly better synchronisation accuracy to enable the transmission of the upcoming 4K video resolution standard. This represents a challenge to EGNSS, which will need to evolve to continue supporting these markets.

6.11 Challenges of using EGNSS in Emerging Applications

Internet-of-Things

GNSS seen as a power sink. Wireless sensors are gaining popularity with the installation of smart devices in smart cities applications. Battery-powered wireless devices enable easy installation but changing batteries frequently is not ideal from an ease-of-use or cost perspective. GNSS is seen as an important power sink because GNSS receivers require a relatively high power consumption. In this regard, the challenge is to promote the use of efficient techniques aimed at reducing the GNSS battery impact. An example is the cloud GNSS processing concept, in which, instead of using the host device’s processing capabilities, cloud GNSS receivers utilise cloud-based processing services, thus offloading most of the processing and energy consuming tasks from the host device.

Cost and size are also important in IoT. GNSS chipsets have a cost of a few euro and cannot be justified in situations where low value items need to be tagged (for some applications sensors are intended to be low-cost disposable devices).

Concurrent technologies. Leveraging on GNSS limitations, new concurrent technologies have landed in the highly competitive IoT market. This is the case of LoraWAN geolocation systems, which are capable of exploiting transmitted packages to calculate the current position without the use of GNSS or GSM. The geolocation is calculated applying a multilateration algorithm on the gateways timestamps from received packages. Offering a better power efficiency than GNSS, it has gained interest in the market. However, the accuracy performances achieved with this technique (~50 meters) cannot be compared with the one achieved with GNSS and therefore it is not suitable for all the applications requiring positioning. The challenge for EGNSS is to leverage on its differentiators to gain market share.

The proposed new telecommunication regulatory framework in the EU intends to modernise the rules applicable to telecom networks. Realising our gigabit/s connectivity objectives, including 5G deployment, may require doubling the investments planned by the sector over the next decade.

Remotely Piloted Aircraft System and Drones

Harmonised EU regulation. EASA is currently developing regulations intended to address the full scope of RPAS operations within the EU over all weight categories. The priority is ensuring that the introduction of RPAS operations does not impact the safety of other airspace users and enables a harmonised deployment across the EU.

The 4th industrial revolution.

Accurate positioning of mobile manufacturing devices will be challenged by its complex industrial and build environments and combined outdoor and indoor situations, bringing about high risks of signal interference.

6.12 Challenges of using EGNSS in Security and Defence

Galileo 2nd generation. The Galileo 2nd generation requirements are expected to be defined during the next years. As such, there is a finite window in which security and defence needs could be integrated into the requirements definition process. This is needed in order to ensure that performance of PNT services in terms of accuracy, continuity, robustness and integrity meet the defence user needs.

Back-up PNT systems. Back-up systems for the security and defence sector have higher performance standards, which involves higher system maintenance costs and potentially diverging requirements from the civil sector. This might further complicate system decommissioning, since for military requirements for security, sovereignty and ownership, they might need to be maintained in spite of the economic impact.

Cross-institutional synergies. Currently, the European Defence Agency is analysing within its own framework the topic of Military Satellite Navigation and is in the process of drafting a document defining high-level military requirements within a wider context of PNT services (not only radio based). As such, there are avenues for pursuing the EGNSS security and defence work strand in a more specialized manner and taking advantage of cross-institutional synergies to chart the needs and potential future use of the services within the sector.

7. CONCLUSIONS

The current radio navigation landscape in Europe relies on both satellite and ground based systems. Over the last decade, satellite navigation systems have quickly become the dominant, or even unique, means for transmitting PNT information to user communities in multiple sectors. Over the next decade, this trend will continue. Two new GNSS "brands", Galileo and BeiDou, will soon reach their full operational capability. The already operating GPS and GLONASS will improve their performance. In total, there will be around 100 operational navigation satellites in orbit providing improved accuracy, availability and security to user communities. Augmentation systems will also evolve to support the new constellations and the signals they relay.

The development of satellite navigation systems is reducing the overall need to use terrestrial systems around the world. In the aviation domain, the Commission is pursuing the development of an EU Air Navigation Strategy to pave the way towards a more modern navigation system. Within this context, the ILS, MLS, VOR and NDB systems will be rationalized or even decommissioned, the extent of which depends on the choices made by different national authorities. In the maritime domain, Loran-C was switched off in 2015.

Location based services using mobile cellular networks are also possible, although at much lower levels of accuracy than what GNSS can offer. The development of the future 5G standards is expected to substantially improve the location performance of this communication system. Interestingly, mobile cellular networks can provide PNT services in environments that are difficult or even impossible for GNSS to work properly in, such as deep indoors, tunnels, underground and urban canyons.

DCF77, a low-frequency system for timing and frequency distribution, is operational since 1959, with the existing contractual regulation extending its use until 2021. The low frequency and high power transmission of DCF77 makes it difficult to jam and allows for the reception of its signals inside buildings.

The full operational capability of Galileo being declared and the deployment of the next generation of EGNOS will lead to a transformation of the radio navigation landscape in Europe, turning it into a truly multi-constellation and multi-frequency environment. Specific characteristics of Galileo, like the ability to authenticate navigation messages, will be crucial for professional and liability applications. In all, users across all sectors will benefit from increased accuracy, availability, robustness, security and safety.

There are, however, some challenges that will need to be addressed. At Earth's surface, the power of GNSS signals is very low, which makes them vulnerable to natural and artificial interference. Especially significant is the vulnerability of GNSS signals to intentional attacks like jamming and spoofing. Because of this, it is generally recognized that, at least for critical applications, GNSS should not be the sole source of PNT information, not even within the new multi-constellation and multi-frequency reality. Alternative PNT systems, not necessarily using radio frequencies, should thus be put in place where the criticality of the application requires it. Requirements for backup PNT systems in each user segment with the open challenge of anticipating future sectoral needs must be analysed.

The European Military Satellite Navigation Policy has a number of commonalities with the EU EGNSS policy. Synergies between defence and space-based PNT should be further explored and could provide avenues for further cooperation such as on user requirements and on R&D of mutual benefit.

The various sectors consulted in this exercise are invited to address the challenges highlighted in this plan, adapting sectoral policies where appropriate. Efforts must now focus on how Europe can optimise its PNT infrastructure in terms of finding the right system mix going forward whilst considering the overall costs, the need to offset risk and the need to deliver continued high performance of PNT services to user communities.

ANNEX 1. Description of Radio Navigation and Timing Systems

Annex 1 describes the basic characteristics of the following radio navigation and timing systems:

- Global Positioning System, GPS.
- GLONASS.
- Galileo.
- BeiDou.
- European Geostationary Navigation Overlay System, EGNOS.
- Ground Based Augmentation System, GBAS.
- Differential GNSS, DGNSS.
- Non-Directional Beacon, NDB.
- VHF Omnidirectional Radio Range, VOR.
- Distance Measuring Equipment, DME.
- Instrument Landing System, ILS.
- Microwave Landing System, MLS.
- Loran-C / Chayka.
- Enhanced Loran, eLoran.
- Differential eLoran, eDLoran.
- Longwave time and frequency distribution systems, DCF77.
- Cellular networks based positioning.
- Iridium-Satelles Time and Location, STL.

Annex 1 also presents the status and expected development plans for each of the systems.

1. Satellite-based Systems

1.1 Global Navigation Satellite Systems

1.1.1 GPS

The Global Positioning System, GPS, is a positioning, navigation and timing system owned by the government of the United States and operated by the United States Air Forces. It is a dual use system, which provides service to civil and military users. The GPS consists of a space segment, a control segment, and a user segment. The GPS works transmitting several radiofrequency signals containing precise timing and location information from a constellation of satellites. Combining the information received from at least four satellites, the user gets an estimation of its position and time. GPS initial operational capability started in 1993. It provides continuous, global coverage, under all weather conditions.

A constellation of satellites in medium Earth orbit form GPS space segment. A minimum of 24 satellites are needed to provide global coverage, although the actual number of satellites in orbit tends to be larger than that, increasing the performance of the system. The satellites are located in six equally spaced orbital planes, inclined 55°, at an altitude of 20.200 km. With this constellation configuration, every point in the surface of the Earth sees at least four GPS satellites at all times, which is necessary to get the positioning information.

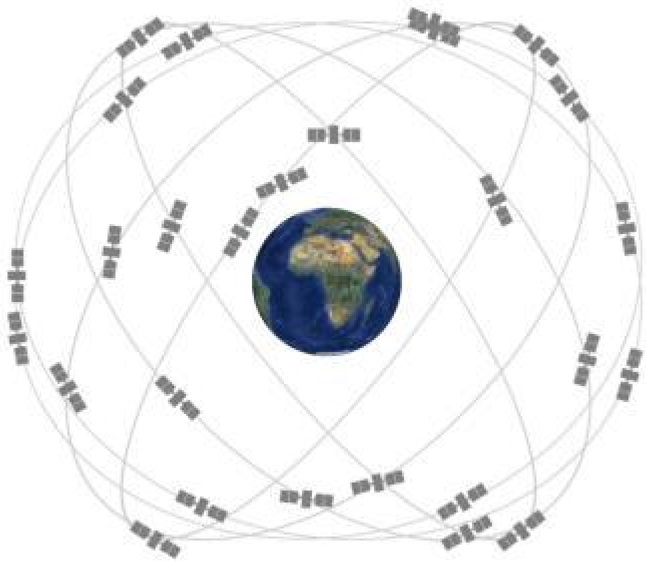


Figure 2 – GPS constellation (Credit: www.gps.gov)

Since the first launch in 1978, the US has been continuously improving the characteristics of GPS satellites. Each generation, or block, of satellites transmits more signals, with improved codes, in more frequencies with respect to the previous one. Modernised satellites include also better components and characteristics: improved atomic clocks, increased power, increased expected lifetime … The result is a better performance and accuracy for both the civil and military users. This evolution process will continue in the future. Figure 3 show some basic characteristics of the different families of GPS satellites.

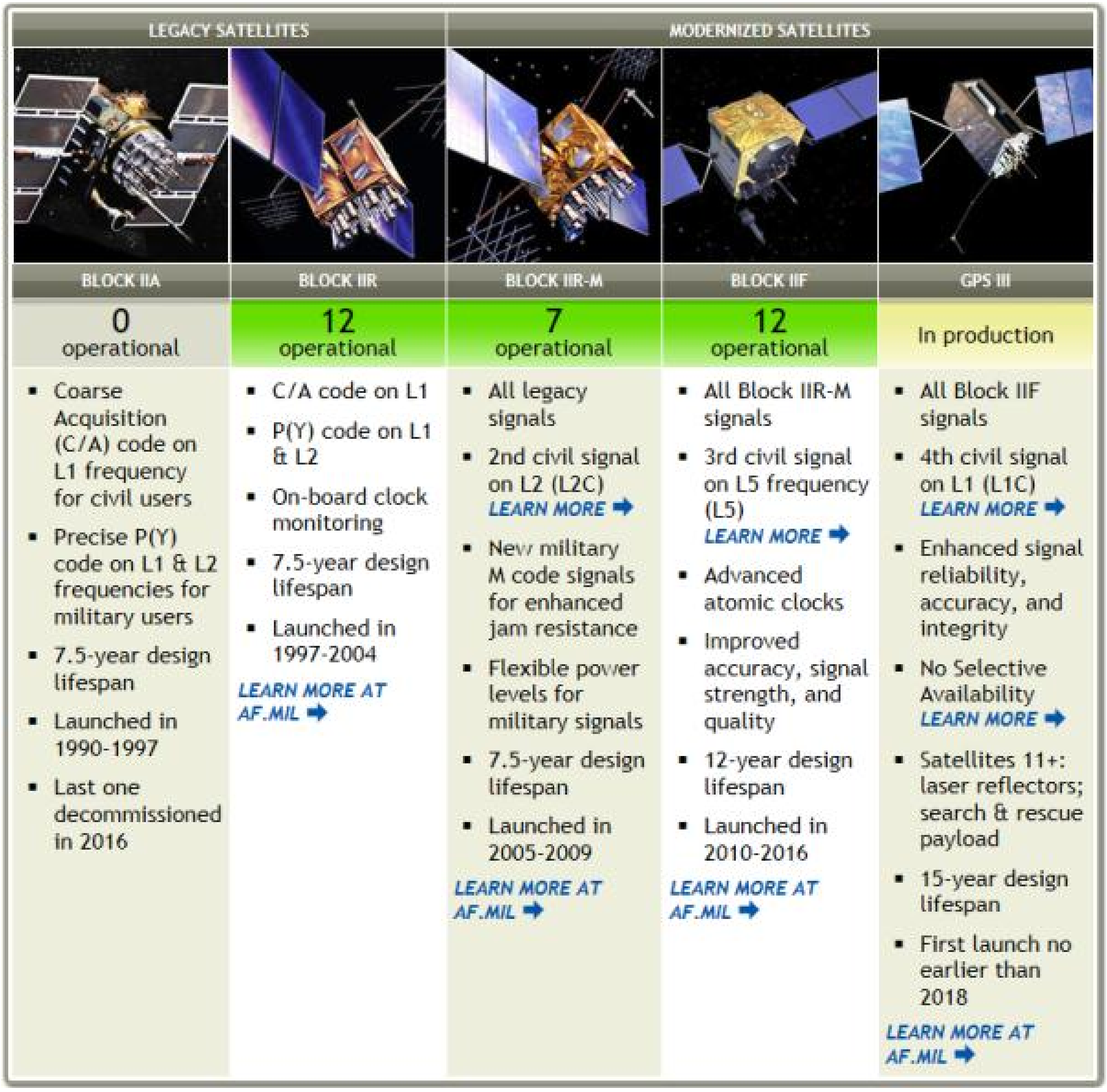


Figure 3 – Evolution of GPS satellites (Credit: www.gps.gov)

The control segment, shown in Figure 4, consists of a worldwide network of ground facilities that track, control and command GPS satellites. The control segment monitors the health status of the satellites, resolves any possible anomaly, controls the orbits of the satellites and adjusts them if necessary, adjusts the on-board clocks, and, in general, performs any task needed to keep the system working properly. It is composed of a Master Control Station (Schriever Air Force Base, Colorado), an alternate Master Control Station (Vanderberg Air Force Base, California), fifteen Monitor Stations (worldwide) and four Ground Antennas (Cape Canaveral, Ascension, Diego Garcia and Kwajalein). GPS control segment is connected to the Air Force Satellite Control Network to increase tracking and command flexibility and robustness.

The user segment consists on the receivers used to receive and decode GPS signals. A receiver gives to the user its three-dimensional location information plus a very precise timing signal.

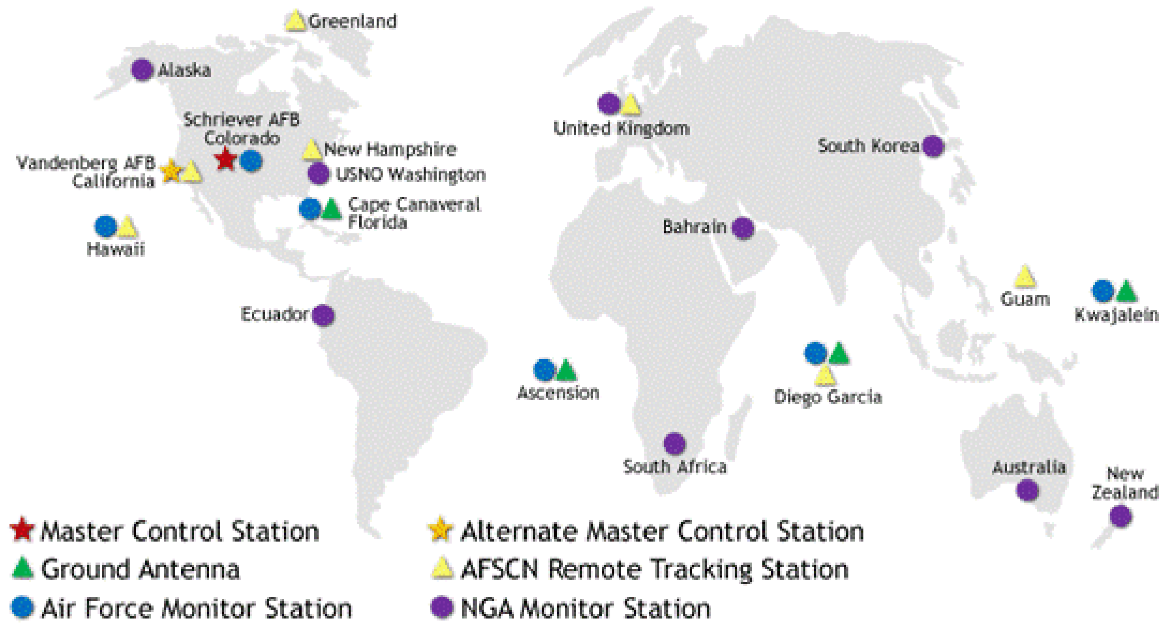


Figure 4 – GPS control segment (Credit www.gps.gov)

Main characteristics

The terrestrial service volume of the GPS constellation comprises from the surface of the Earth up to an altitude of 3000 km. Table 1 and Figure 5 show the principal characteristics of GPS signals.

Table 1 – Principal characteristics of GPS signals

L1				
Signal	C/A	L1C	P(Y)	M
Frequency (MHz)	1575.42	1575.42	1575.42	1575.42
Access Technique	CDMA	CDMA	CDMA	CDMA
Modulation	BPSK(1)	TMBOC(6,1,1/11)	BPSK(10)	$BOC_{sin}(10,5)$
Minimum received power [dBW]	-158.5	-157	-161.5	N.A.

L2				
Signal	L2 C	P(Y)	M	
Frequency (MHz)	1227.6	1227.6	1227.6	
Access Technique	CDMA	CDMA	CDMA	
Modulation	BPSK(1)	BPSK(10)	$BOC_{sin}(10,5)$	
Minimum received power [dBW]	-161.5	-160	N.A.	
L5				
Signal	L5			
Frequency (MHz)	1176.45			
Access Technique	CDMA			
Modulation	BPSK(10)			
Minimum received power [dBW]	-157.9			

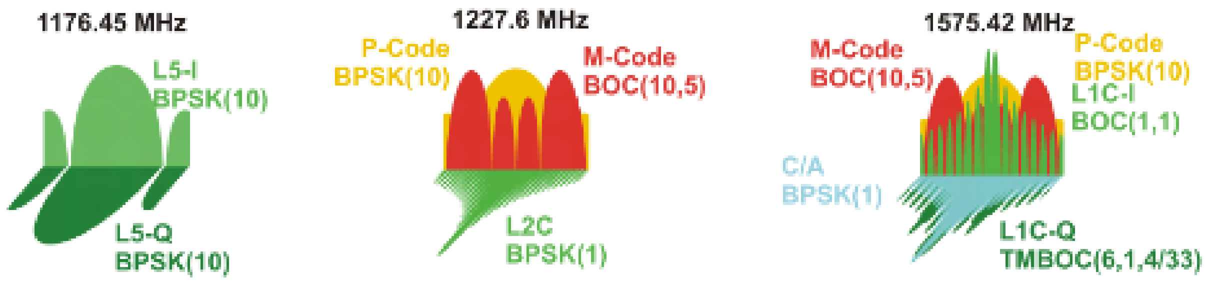


Figure 5 – GPS signals (Credit: Navipedia)

The error in position and time users will experience depends on the characteristics of the signals transmitted by GPS satellites, their propagation, and the performance of the receiver employed. Table 2 shows the GPS SPS position and time accuracy standards for representative user conditions.

Table 2 – GPS SPS position and time accuracy standards

Global Average Position Domain Accuracy: Horizontal error (95%) ≤ 9m Vertical error (95%) ≤ 15m	Standard based on a measurement interval of 24 hours averaged over all points in the service volume
Worst Site Position Domain Accuracy:	Standard based on a measurement interval of

Horizontal error (95%) ≤ 17m Vertical error (95%) ≤ 37m	24 hours for any point in the service volume.
Time Transfer Domain Accuracy: Time transfer error (95%) ≤ 40ns (SIS only)	Standard based on a measurement interval of 24 hours averaged over all points in the service volume

Table 3 shows GPS SPS specifications for availability, integrity and continuity.

Table 3 – GPS SPS specifications

Availability[20]	99%
Integrity	≥ 1 - 1×10^{-5} per hour
Continuity	≥ 0.9998 per hour

To exploit GPS signals, users just need to have a compatible receiver, meaning that GPS can serve to an unlimited number of users at the same time.

Status and modernisation plans

On February 2018, there were 31 operational GPS satellites, 12 from Block IIR, 7 from Block IIR-M, and 12 from Block IIF, as indicated in Figure 3. Therefore, only signals L1 C/A, L1 P(Y) and L2 P(Y) have reached Full Operational Capability. There are 19 satellites broadcasting signals L2C, L1M and L2M. There are 12 satellites broadcasting L5 signals. The first GPS III satellite launch is planned for the second half of 2018. Depending on the pace of GPS III launches, we can expect the Full Operational Capability for L2C on 2020 and for L5 on 2026. L1C will reach Full Operational Capability around 2030[21]. Figure 6 shows the expected evolution of GPS signals.

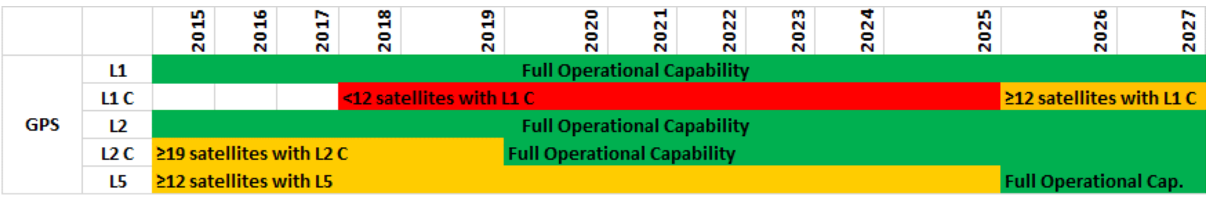


Figure 6 – Expected GPS signal availability

20 From the US FRP

21 GPS Update to PNT Advisory Board, 15 November 2017, Global Positioning Systems Directorate

Figure 7 shows the SPS signal-in-space performance achieved during the last 15 years. We see a continuous decrease in User Range Error, URE, between years 2001 and 2015, which is a consequence of the constant evolution of the GPS system. We also see that the achieved accuracy is better than the established in the performance standard, almost a factor of 3 for year 2015 (2.8 m worst of any healthy satellite measured vs. 7.8 m specifications).

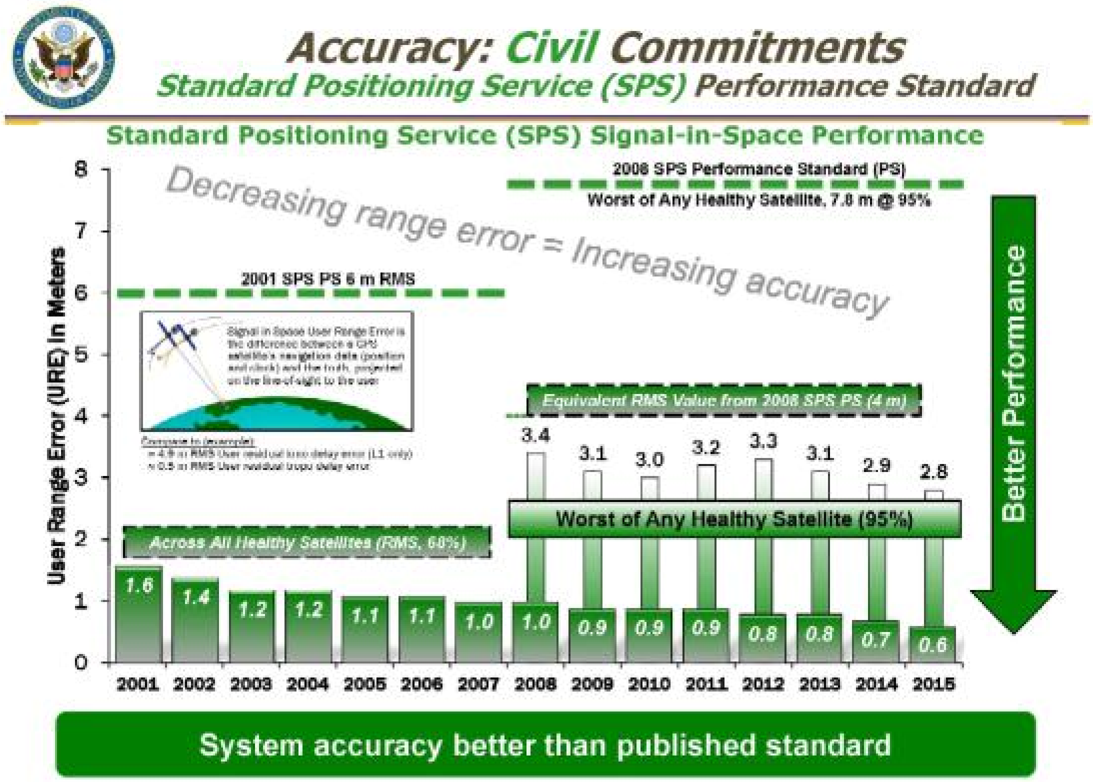


Figure 7 – GPS SPS accuracy evolution (Credit: GPS Directorate)

The University of Texas at Austin examined the performance of the GPS SPS during year 2016[22]. They report a yearly 95% percentile value of SIS RMS URE of 1.22 metres for Block IIR/IIR-M satellites (2.45 metres worst satellite), and 1.39 metres for Block IIF satellites (2.46 metres worst satellite).

Exploitation strategy

GPS has two types of services, the GPS SPS (civil) and the GPS PPS (restricted).

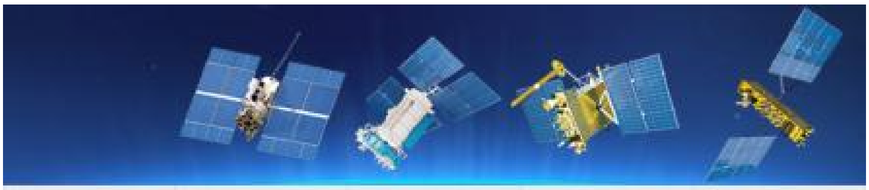
Access to the GPS SPS is free of direct user fees, for civil, commercial and scientific use. It is policy of the US to keep the GPS SPS free of fees. To access the GPS SPS service, users only need to have an adequate GPS receiver.

Access to the GPS PPS is restricted to the US Government, the US armed forces and its selected allies.

[22] An analysis of GPS SPS performance for 2016. TR-SGL-17-06. May 2017

1.1.2 GLONASS

GLONASS is a satellite-based radionavigation system owned and operated by the Russian Federation. It is a dual use system, providing service to civil and military users. The working principle of GLONASS is similar to that of the GPS: a constellation of satellites transmits radio signals containing precise location and timing information. Receiving the signals from at least four satellites, users can estimate their three dimensional position and a very precise time signal. GLONASS consists on a space segment, a control segment and a user segment. As in the case of GPS, a minimum of 24 satellites are needed to provide global coverage. The satellites are located in three orbital planes inclined 63.8° at an altitude of 19140 km. This configuration guarantees global coverage on the Earth's surface, and it is adapted to the high latitudes of the Russian Federation. GLONASS is in continuous evolution. Similarly to GPS, newer satellite blocks have improved characteristics with respect to the older ones. Figure 8 shows the evolution of GLONASS satellites. New satellites transmit more signals in more frequencies than older ones. They also include more precise clocks and better components, which results in a general improvement of service delivery to the final user.



CAPABILITIES	GLONASS	GLONASS-M	GLONASS-K	GLONASS-K2
Time of Deployment	1982-2005	2003-2016	2011-2018	2017+
Status	Decommissioned	In use	Design maturation based on in-orbit validation	In development
Nominal Orbit Parameters	Circular Altitude - 19,140 km Inclination - 63,8° Period - 11 h 15 min 44 sec			
Number of Satellites in the Constellation (Used for Navigation)	24			
Number of Orbital Planes	3			
Number of Satellites in a Plane	8			
Launchers		Soyuz-2.1b, Proton-M		
Design Lifetime, years	3.5	7	10	10
Mass, kg	1500	1415	935	1600
Dimensions, m		2,71x3,05x2,71	2,53x3,01x1,43	2,53x6,01x1,43
Power, W		1400	1270	4370
Platform Design	Pressurized	Pressurized	Unpressurized	Unpressurized
Clock Stability, as per Specification/Observed	$5*10^{-13}$ / $1*10^{-13}$	$1*10^{-13}$ / $5*10^{-14}$	$1*10^{-13}$ / $5*10^{-14}$	$1*10^{-14}$ / $5*10^{-15}$
Signal Type	FDMA	FDMA (+CDMA for SVs 755-761)	FDMA and CDMA	FDMA and CDMA
Open Access Signals (for FDMA Signals Center Frequency Values are Provided)	L1OF (1602 MГц)	L1OF (1602 MГц) L2OF (1246 MГц) L3OC (1202 MГц) for SVs 755+	L1OF (1602 MГц) L2OF (1246 MГц) L3OC (1202 MГц) L2OC (1248 MГц) for SVs 17L+	L1OF (1602 MГц) L2OF (1246 MГц) L1OC (1600 MГц) L2OC (1248 MГц) L3OC (1202 MГц)
Restricted Access Signals	L1SF (1592 MГц) L2SF (1237 MГц)	L1SF (1592 MГц) L2SF (1237 MГц)	L1SF (1592 MГц) L2SF (1237 MГц) L2SC (1248 MГц) for SVs 17L+	L1SF (1592 MГц) L2SF (1237 MГц) L1SC (1600 MГц) L2SC (1248 MГц)
Satellite Crosslinks RF Laser	 — —	 + —	 + —	 + +
Search and Rescue	—	—	+	+

Figure 8 – Evolution of GLONASS satellites (Credit: www.GLONASS-iac.ru)

The control segment of GLONASS, shown in Figure 9, consists on a network of monitoring stations, uplink and downlink communication antennas, laser tracking stations and a system control centre. The control segment monitors the status and performance of the satellites, resolves any potential anomaly it might appear, controls and adjusts the orbit of the satellites, uploads the updated navigation information, and, in general, performs any task needed to keep the system operational with the best possible service to the user. Most of the control segment of GLONASS is located within the territory of the Russian Federation. There are plans to extend GLONASS control segment outside the Russian territory.

Figure 9 – GLONASS control segment (Credit: Russian Federal Space Agency)

The user segment consists on the receiver equipment needed to receive and process GLONASS signals.

Main characteristics

GLONASS has global coverage over the surface of the Earth, under all weather conditions, providing positioning, navigation and timing. Table 4 and Figure 10 show the principal characteristics of GLONASS signals.

Table 4 – Principal characteristics of GLONASS signals

L1				
Signal	C/A	P	L1 OC	L1 OCM
Frequency (MHz)	1598.0625 to 1605.375	1598.0625 to 1605.375	1600.995	1600.995
Access Technique	FDMA	FDMA	CDMA	CDMA
Modulation	BPSK(0.511)	BPSK(5.11)	BPSK(1)	BOC(5,2.5)
Minimum received power [dBW]	-161	N.A.		
L2				
Signal	C/A	P	L2 OC	L2 OCM
Frequency (MHz)	1242.9375 to 1248.625	1242.9375 to 1248.625	1248.06	1248.06

Access Technique	FDMA	FDMA	CDMA	CDMA
Modulation	BPSK(0.511)	BPSK(5.11)	BPSK(1)	BOC(5,2.5)
Minimum received power [dBW]	-167	N.A.		
L3				
Signal	L3 OC			
Frequency (MHz)	1202.025			
Access Technique	CDMA			
Modulation	QPSK(10)			
L5				
Signal	L5 OC			
Frequency (MHz)	1176.45			
Access Technique	CDMA			
Modulation	QPSK(10)			

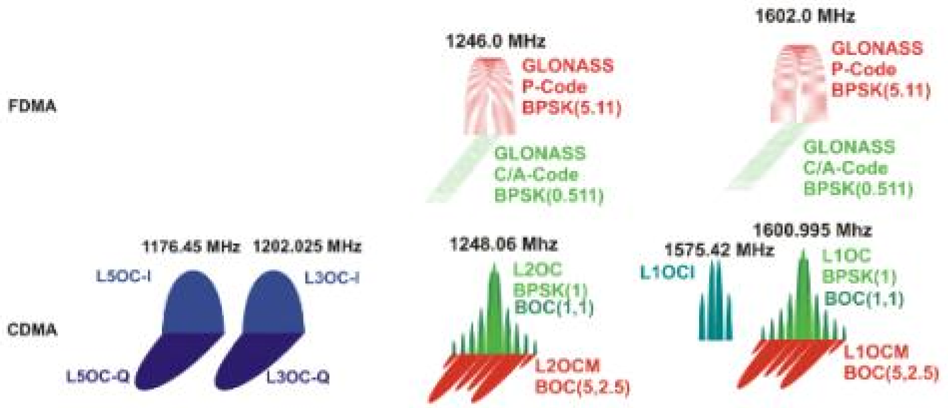


Figure 10 – GLONASS signals (Credit: Navipedia)

To exploit GLONASS signals, users just need to have a compatible receiver, meaning that GLONASS can serve to an unlimited number of users at the same time.

Status and modernisation plans

On February 2018, there were 24 operational GLONASS satellites in orbit and one in flight tests phase. All satellites belong to the GLONASS-M block, except two that belong to the GLONASS-K block.

From 2019, the Russian Federation plans to replenish the constellation with the modernised GLONASS-K1 and GLONASS-K2 satellites. Figure 11 and Figure 12 show the expected availability of GLONASS signals. L1 and L2 FDMA have reached Full Operational Capability. L3 CDMA is expected to reach FOC in 2022, L2 CDMA in 2025 and L1 CDMA around 2030.

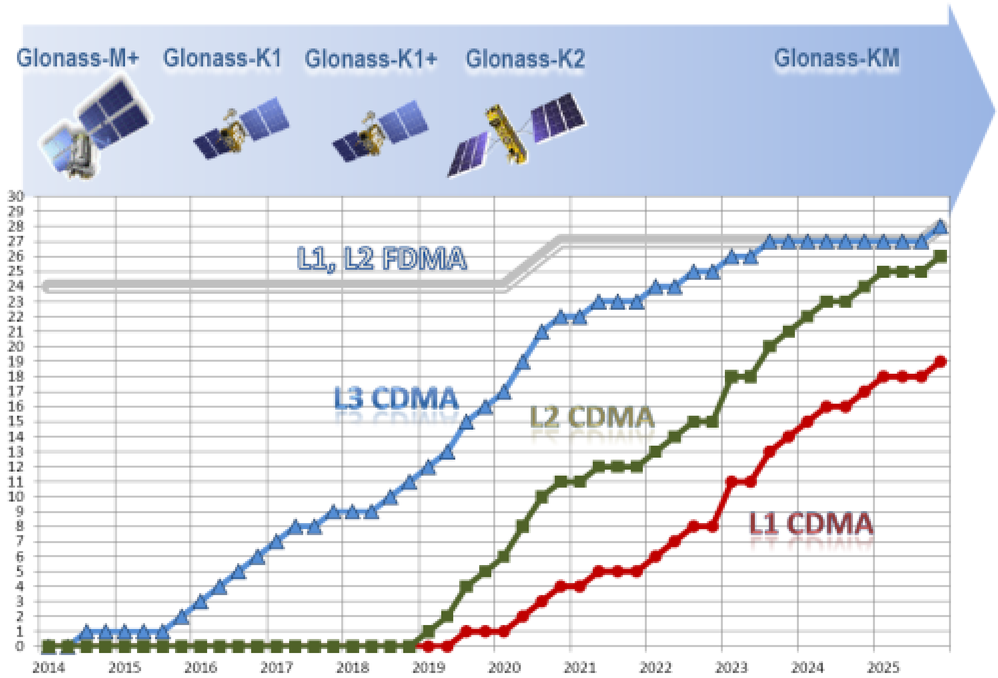


Figure 11 – Expected GLONASS signal availability (Credit: Russian Federal Space Agency)

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Glonass	L1 F	Full Operational Capability											
	L1 C					<12 satellites with L1 C				>=12 satellites with L1 C			
	L2 F	Full Operational Capability											
	L2 C					<12 satellites with L2 C		>=12 satellites with L2 C				Full Operational Capability	
	L3 C	<12 satellites with L3 C				>=12 satellites with L3 C			Full Operational Capability				

Figure 12 – Expected GLONASS signal availability

Figure 13 shows the Signal-In-Space User Range Error, SIS URE, achieved by GLONASS constellation between July and September 2017. The SIS URE ranges between 1 and 2 metres, with an average of approximately 1.5 metres.

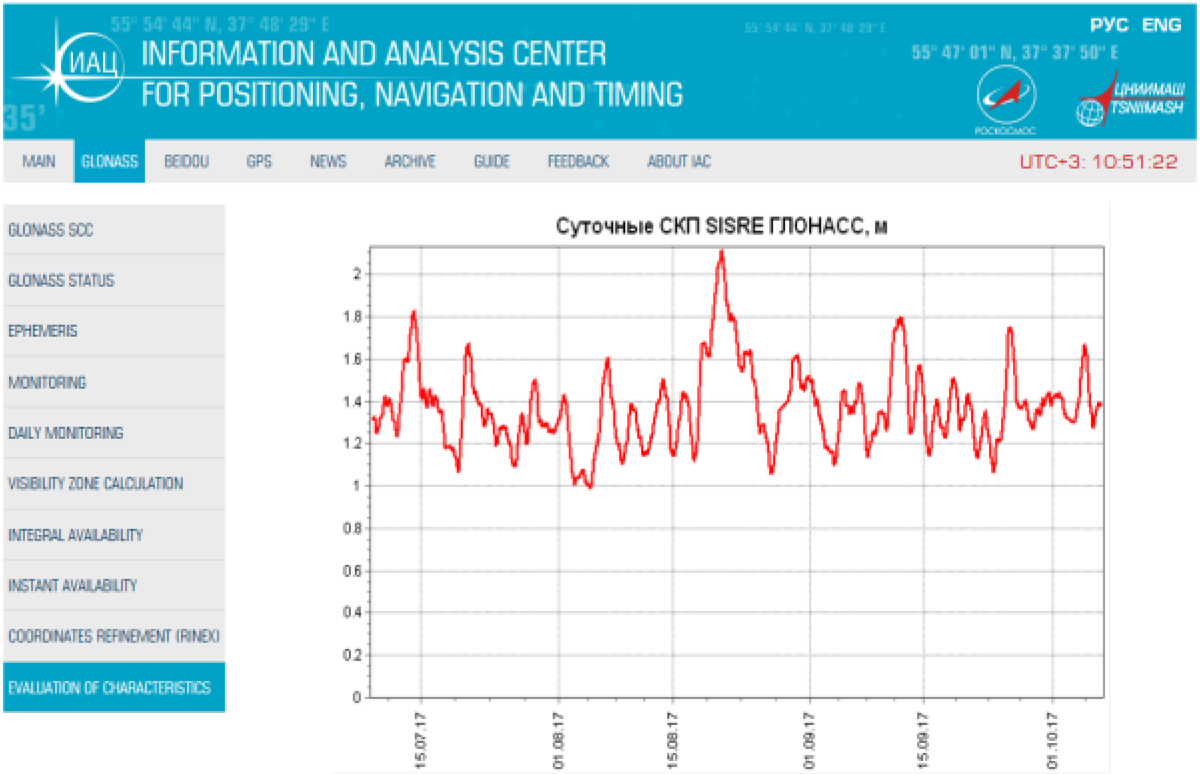


Figure 13 – GLONASS SIS user range error (Credit: Russian Federal Space Agency)

Exploitation strategy

GLONASS has two types of services, a civil one and a restricted one.

Access to GLONASS civil service is free and unlimited, and it is policy of the Russian Federation to keep it like that. To access GLONASS civil service, users only need to have an adequate GLONASS receiver. Access to GLONASS restricted service is limited to Russian government and armed forces.

1.1.3 Galileo

Galileo is the European global navigation satellite system, funded and managed by the European Commission. It is the only GNSS completely managed by civil authorities. Galileo services will be, however, adapted to both civil and military users, through an open service, a high accuracy service and a public regulated service. Galileo consists of a space segment, a ground segment and a user segment. To provide global coverage, at least 24 satellites are needed. The satellites are situated in circular orbits in three equally spaced orbital planes, with an inclination of 56°, at an altitude of 23.222 km. Since the beginning of the programme, three types of satellites have formed the space segment of Galileo:

- Giove-A and Giove-B. They were experimental satellites used to test different technologies and to reserve the frequencies assigned to Galileo by ITU.

- Galileo In-Orbit Validation, IOV. They were the four first satellites of the operational Galileo constellation, used to validate the system design.
- Galileo Full Operational Capability, FOC. They will form, together with the four Galileo IOV, the full Galileo constellation. OHB is the prime contractor for Galileo FOC satellites and Figure 14 shows its principal characteristics.

Item	Parameter
Total Launch Mass	732.8 kg
Body Dimensions	2.5 x 1.2 x 1.1 m
Span Solar Generator	14.67 m
Overall Dimensions (Launch)	2.91 x 1.70 x 1.40 m
Orbit	MEO, r = 29,600km, I = 56°, 3 orbit planes with RAAN spacing of 120°, at EoL transfer to graveyard orbit
Lifetime	> 12 years on-orbit, > 5 years ground storage
Layout	Satellite consists of 7 modules, incl. "plug-in" propulsion module (> simple interfaces, enables parallelised MAIT)
Navigation Signal	3 bands (E5, E6, E1)
• Minimum EIRP (EOC)	E5 - 32.57 dBW / E6 - 33.20 dBW / E1 - 35.06 dBW
• Bandwidth	E5 - 92.07 MHz / E6 - 50.00 MHz / E1 - 50.00 MHz
Clock Frequency Stability	Passive Hydrogen Maser: < 4.5×10^{-14} @ 30000 s Rubidium Atomic Freq. Standard: < 5.1×10^{-14} @ 10000 s
SAR Transponder (Search- and Rescue service COSPAS-SARSAT)	UHF Receiver 406 MHz, forward channel L-Band 1,544 MHz
Common Security Unit	Protection against unauthorised access to satellite platform and navigation payload
Power	
• Subsystem Layout	50 V, regulated bus; Li-Ion battery, 3.8 kWh
• Solar Generator	2 Wings, 2 Panels each, Triple Junction GaAs, 1.9 kW (EoL)
Satellite Reliability	> 0.88 / 12 years

Figure 14 – Galileo FOC satellite characteristics (Credit: OHB)

Galileo's ground segment consists of two control centres (Oberpfaffenhofen and Fucino), five Telemetry, Tracking and Command stations (Kiruna, Kourou, Redu, Reunion Island and New Caledonia Island), a worldwide network of sensor stations and a worldwide network of uplink stations. Figure 15 depicts the working principle of Galileo's ground segment. TT&C stations receive status and health information from the satellites. In parallel, sensor stations receive the navigation signals. All these information is sent to both control centres, where it is processed and analysed. The control centres calculate the updated navigation message, as well as commands to the satellites to correct, for example, for any orbital drift or an anomalous situation in a satellite platform. The updated navigation information and the commands to the satellites are transmitted through the uplink and TT&C stations, respectively. This is a continuous process, which aims to maintain the system providing the best possible performance and service.

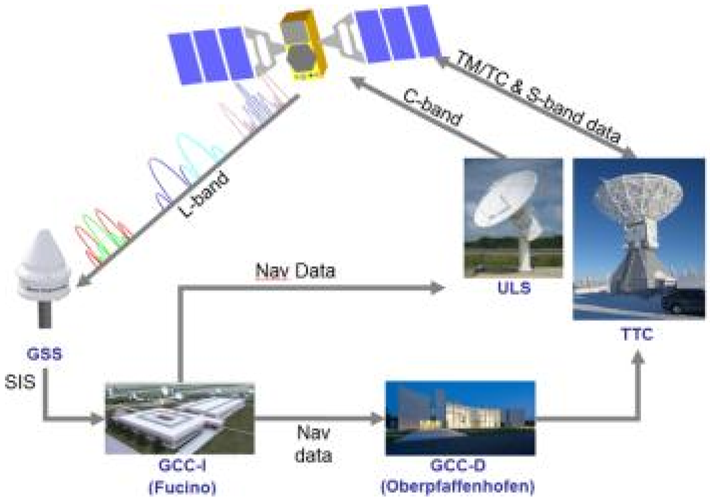


Figure 15 – Galileo ground segment (Credit: ESA)

Main characteristics

Galileo has global coverage over the surface of the Earth, and provides positioning, navigation and timing information under all weather conditions. Table 5 and Figure 16 show the principal characteristics of Galileo signals.

Table 5 – Principal characteristics of Galileo signals

E1		
Signal	E1 OS	E1 PRS
Frequency (MHz)	1575.42	1575.42
Access Technique	CDMA	CDMA
Modulation	CBOC(6,1,1/11)	BOC_{cos}(15,2.5)
Minimum received power [dBW]	-157	
E6		
Signal	E6 CS	E6 PRS
Frequency (MHz)	1278.75	1278.75
Access Technique	CDMA	CDMA
Modulation	BPSK(5)	BOC_{cos}(10,5)
Minimum received power [dBW]	-155	
E5		

Signal	E5a	E5b
Frequency (MHz)	1191.795	1191.795
Access Technique	CDMA	CDMA
Modulation	AltBOC(15,10)	AltBOC(15,10)
Minimum received power [dBW]	-155	

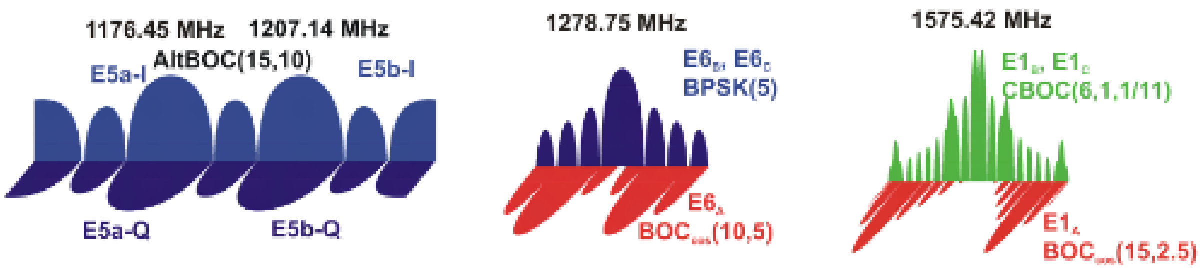


Figure 16 – Galileo signals (Credit: Navipedia)

The document "Galileo Initial Services – Open Service – Service Definition Document" defines the Minimum Performance Levels, MPLs, of the Galileo Open Service to be provided during the Galileo Initial Services provision phase. Table 6 shows Galileo signal-in-space ranging accuracy MPLs.

Table 6 - Galileo SIS Ranging Accuracy MPLs

Galileo SIS ranging accuracy MPL (Any satellite)	**Conditions and Constraints**
For each single frequency: ≤ 7m (95%) global average, over all AODs	Calculated over a period of 30 days For any healthy OS SIS above a minimum elevation angle of 5 degrees Including Broadcast Group Delay errors Propagation and user contributions excluded Neglecting single frequency ionospheric delay model errors
For each double frequency combination: ≤ 7m (95%) global average, over all AODs	Calculated over a period of 30 days For any healthy OS SIS above a minimum elevation angle of 5 degrees Propagation and user contributions excluded
Galileo SIS ranging accuracy MPL (All satellites)	**Conditions and Constraints**
For each single frequency:	Calculated over a period of 30 days

≤ 2m	Average, over the constellation, of the Galileo SIS Ranging Accuracy (95%) of each Healthy SIS
For each double frequency combination: ≤ 2m	Calculated over a period of 30 days Average, over the constellation, of the Galileo SIS Ranging Accuracy (95%) of each Healthy SIS

Table 7 shows Galileo SIS UTC Time and Frequency Dissemination Accuracy MPLs.

Table 7 - Galileo SIS UTC Time and Frequency Dissemination Accuracy MPLs

Galileo SIS UTC Time Dissemination Accuracy MPL	**Conditions and Constraints**
For each single frequency and double frequency combination: < 30ns (95%) over all AODs	For any healthy OS SIS At any user location Normalised annually Propagation and user contributions excluded.
Galileo SIS UTC Frequency Dissemination Accuracy MPL	**Conditions and Constraints**
For each single frequency and double frequency combination: $< 3x10^{-13}$ (95%) over all AODs	For any healthy OS SIS At any user location Normalised annually Propagation and user contributions excluded

The Galileo Initial Services OS SDD will be updated in the future to reflect further changes and improvements of the Galileo Open Service, in particular during the deployment of the Galileo system infrastructure, until the Full Operational Capability is achieved.

To exploit Galileo signals, users just need to have a compatible receiver, meaning that Galileo can serve to an unlimited number of users at the same time.

Status and modernisation plans

Galileo is under development phase. On February 2018, four IOV satellites and eighteen FOC satellites form the constellation[23]. The European Commission declared the Initial Services of Galileo in December 2016, and plans to declare the Full Operational Capability in 2020. Figure 17 shows the expected availability of Galileo signals.

23 https://www.gsc-europa.eu/system-status/Constellation-Information

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Galileo	E1	<12 satellites with E1		>=12 satellites with E1			Full Operational Capability						
	E5	<12 satellites with E5		>=12 satellites with E5			Full Operational Capability						
	E6	<12 satellites with E6		>=12 satellites with E6			Full Operational Capability						

Figure 17 – Expected Galileo signal availability

Similarly to GPS and GLONASS, Galileo may also evolve in the future, with the launch of a second generation of Galileo satellites. However, we have to note that the political decision on the evolution of Galileo is not yet taken. Today, several scenarios for the evolution of Galileo have been developed and will be analysed in the coming years. The final decision on evolution should be made no later than 2020, once all aspects (architecture, technological choices, benefits and costs, available budget in next MFF) will have been analysed in depth.

Exploitation strategy

Galileo will have four services: the Open Service, the High Accuracy Service, the Public Regulated Service and the Search and Rescue service.

Galileo Open Service will be free of charge to the users. To access it, users will only need to have an adequate Galileo receiver.

Galileo High Accuracy Service can be encrypted in order to control the access. It will provide higher accuracy and integrity than the Open Service. Galileo High Accuracy Service will also be free of charge to the users. Additionally, authentication of the High Accuracy Service will be possible after paying a fee.

Galileo Public Regulated Service will also be encrypted. It will provide increased accuracy, integrity, continuity and resistance to interference, jamming and spoofing. The Public Regulated Service will be restricted to Member States, the Council, the European Commission and the European External Action Service and, where appropriate, European Union agencies. Under certain conditions, third countries and international organisations may access this service.

Galileo will also contribute to COSPAS-SARSAT, an international satellite-based search and rescue distress alert detection system.

1.1.4 BeiDou

BeiDou is a global navigation satellite system owned and developed by China's authorities. It is a dual-use system, which will satisfy the needs of both civil and governmental users. As the rest of GNSS, BeiDou consists on a space segment, a ground segment and a user segment. The space segment of BeiDou is composed of satellites in different orbits, which is a unique characteristic among GNSS. BeiDou constellation, shown in Figure 18, is designed to be formed by 5 geostationary satellites, 3 inclined geostationary satellites and 27 satellites in medium Earth orbit. The GEO satellites are at 58.75°E, 80.0°E, 110.5°E, 140.0°E and 160.0°E. The IGSO satellites are evenly distributed in an orbit with an altitude of 36.000km, an inclination of 55° and an intersection point at 118.0°E. The MEO satellites are evenly distributed in circular orbits on three orbital planes, with an altitude of 21.500 km and an inclination of 55°.

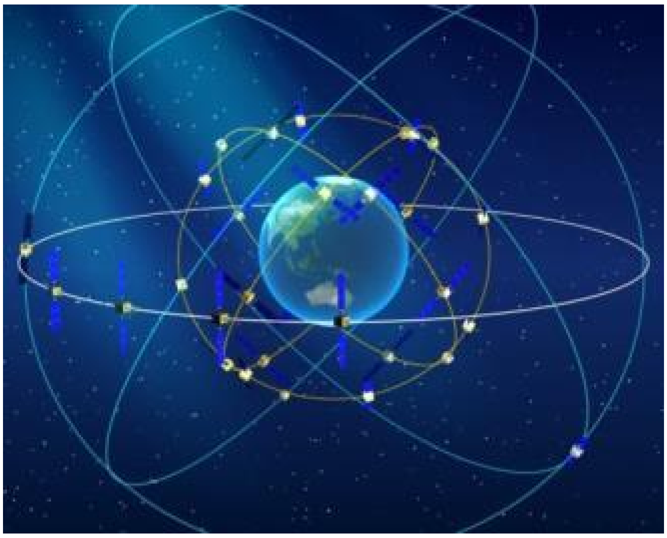


Figure 18 – BeiDou constellation

The ground segment of BeiDou consists on a control station, upload stations and a network of monitoring stations. The working principle of the ground segment is the same as with the other GNSS. The monitoring stations check the quality of the navigation signals and the status of the satellites, and send this information to the control centre. The control centre processes this information, it generates the new navigation message, and the commands needed to keep the satellites working correctly. The upload stations transmit this information to the satellites.

The user segment consists on the equipment needed to receive and process BeiDou signals.

Main characteristics

BeiDou has global coverage over the surface of the Earth, under all weather conditions, providing positioning, navigation and timing. Table 8 and Figure 19 show the principal characteristics of BeiDou signals.

Table 8 – Principal characteristics of BeiDou signals

B1				
Signal	B1-I(OS)	B1-Q(AS)	B1-C	B1
Frequency (MHz)	1561.098	1561.098	1575.42	1575.42
Access Technique	CDMA	CDMA	CDMA	CDMA

Modulation	BPSK(2)	BPSK(2)	MBOC(6,1,1/11)	BOC(14,2)
B3				
Signal	B3-I(AS)	B3-Q(AS)	B3-A(AS)	B3(AS)
Frequency (MHz)	1268.52	1268.52	1268.52	1268.52
Access Technique	CDMA	CDMA	CDMA	CDMA
Modulation	BPSK(10)	BPSK(10)	BOC(15,2.5)	BPSK(10)
B2				
Signal	B2-I(OS)	B2-Q(AS)	B2a	B2b
Frequency (MHz)	1207.14	1207.14	1176.46	1207.14
Access Technique	CDMA	CDMA	CDMA	CDMA
Modulation	BPSK(2)	BPSK(10)	AltBOC(15,10)	AltBOC(15,10)

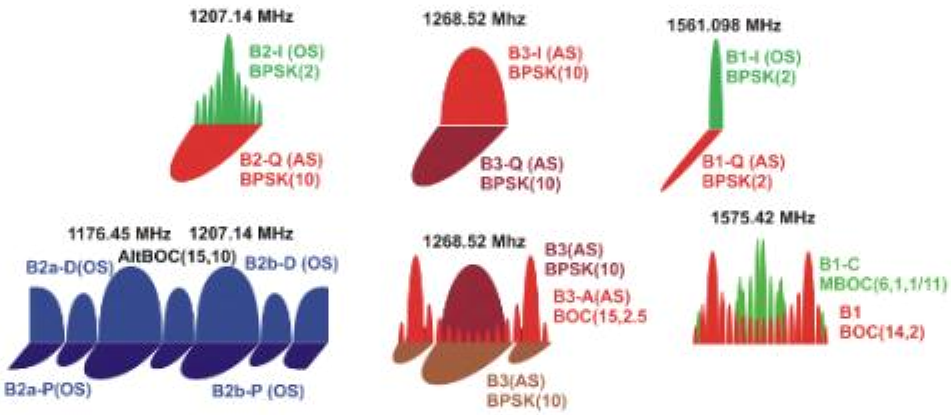


Figure 19 – BeiDou signals (Credit: Navipedia)

China Satellite Navigation Office published in 2013 the “BeiDou Navigation Satellite System Open Service Performance Standard”. We reproduce in Table 9 the values for position, velocity and timing accuracy.

Table 9 – BeiDou specifications

Horizontal accuracy (95%)	≤ 10 m	Statistical position/velocity/time error for any point in the service volume over any 24-hour interval.
Vertical accuracy (95%)	≤ 10 m	
Velocity accuracy (95%)	≤ 0.2 m/s	

Time accuracy (95%)	≤ 50 ns	
Position availability	≥ 0.95	Any point in the service volume over any 24-hour interval

To exploit BeiDou signals, users just need to have a compatible receiver, meaning that BeiDou can serve to an unlimited number of users at the same time.

Status and modernisation plans

Chinese authorities reported the launch, on March 30th 2016, of the 17th satellite of the BeiDou constellation[24]. Over 2017 and early 2018, new BeiDou satellites have been launched. However, there is little information about the operational status of the constellation. The same authorities plan to complete the constellation by 2020. Figure 20 shows the expected availability of BeiDou signals.

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
BeiDou	B1	>=12 satellites with B1					Full Operational Capability						
	B2	>=12 satellites with B2					Full Operational Capability						
	B3	>=12 satellites with B3					Full Operational Capability						

Figure 20 – Expected BeiDou signal availability

Exploitation strategy

BeiDou will have two types of services, a civil one and a restricted one.

Access to BeiDou civil service is free and unlimited, and it is policy of the Chinese authorities to keep it like that. To access BeiDou civil service, users only need to have an adequate BeiDou receiver.

Access to BeiDou restricted service is limited to Chinese authorities.

1.2 Augmentations to Global Navigation Satellite Systems

1.2.1 EGNOS

The European Geostationary Navigation Overlay System, EGNOS, is a regional satellite-based augmentation system for the GPS SPS. The European Union and the GSA are the owner and

24 http://www.beidou.gov.cn/2015/04/01/20150401b4b91ddc213a45129a665ea3272b5aed.html

programme manager of EGNOS, respectively. EGNOS transmits a signal at L1 (1575.42 MHz) with corrections for the GPS SPS, increasing its accuracy and integrity. EGNOS infrastructure consists on the following elements:

- A ground network of 39 Ranging and Integrity Monitoring Stations, RIMS.
- Six Navigation Land Earth Stations, NLES.
- Two mission control centres.
- Signal transponders on three geostationary satellites (Inmarsat 3F2 AOR-E, Astra 5B, and Astra SES-5).
- A Performance Assessment and Checkout Facility, PACF.
- An Application Specific Qualification Facility, ASQF.

Figure 21 depicts the working principle of EGNOS. The ranging and integrity monitoring stations continuously estimate the clock errors and the ionospheric delay data associated with the GPS SPS signals. They send this information to the control centre, where it is processed and messages with the correction parameters are generated. The navigation land Earth stations transmit the signal coded with the corrections to the three geostationary satellites that provide EGNOS services, which broadcast it to their coverage area. Users with adequate equipment receive the standard GPS signals, and, additionally, the correction signal provided by EGNOS. The result is an increased accuracy and integrity with respect to the stand-alone GPS service.

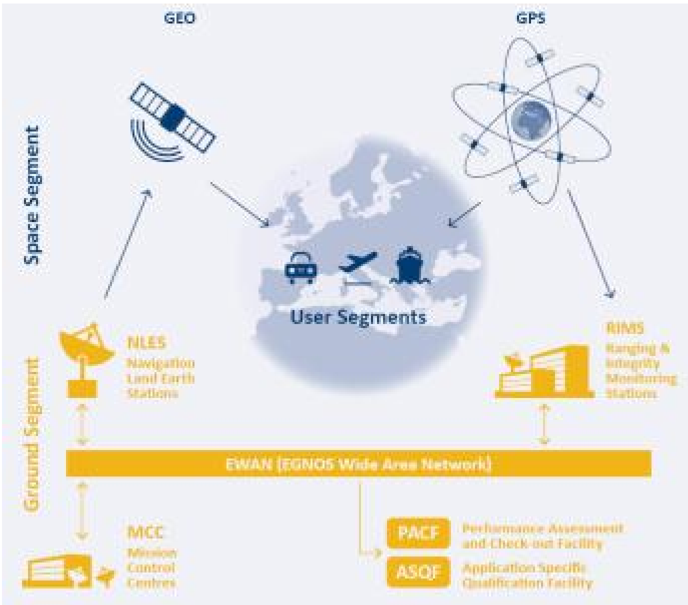


Figure 21 – EGNOS architecture (Credit: GSA)

Main characteristics

EGNOS provides coverage over the European territory, under all weather conditions. Figure 22 shows the open service availability map.

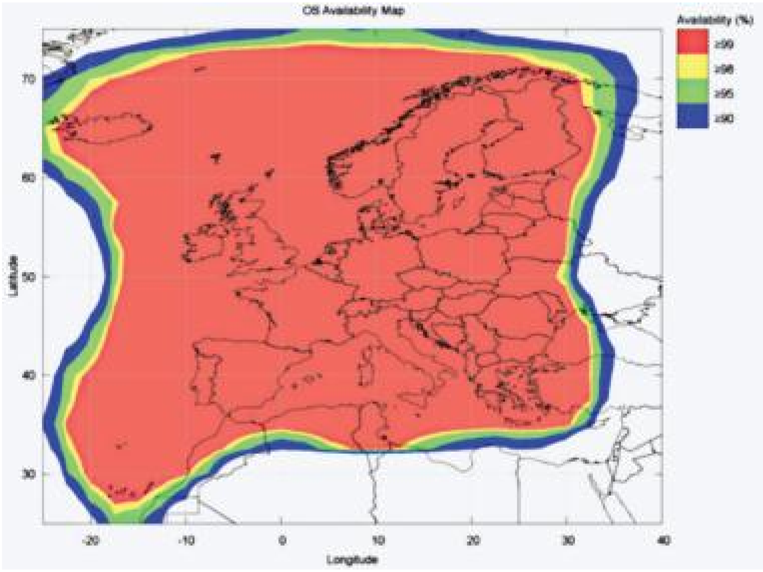


Figure 22 – EGNOS OS availability map (Credit: GSA)

EGNOS satellites transmit right-hand circularly polarised signals in L band at 1575.42 MHz. The broadcasted signal is a combination of a 1023-bit PRN navigation code of the GPS family and a 250 bits per second navigation data message carrying the corrections and integrity data. For elevations higher than 5°, the level of the received RF signal is within the range of –161dBW to –153dBW. At any point in time, at least two of the three satellites broadcast an operational EGNOS signal. Table 10 shows the accuracy of the EGNOS open service.

Table 10 – EGNOS OS accuracy[25]

Horizontal error	≤ 3m 95%
Vertical error	≤ 4m 95%
Timing error	≤ 20ns (3σ)

To exploit EGNOS signals, users just need to have a compatible receiver, meaning that EGNOS can serve to an unlimited number of users at the same time

Status and modernisation plans

The EGNOS open service has been available since 1st October 2009.

The EGNOS safety-of-live service has been available since 2nd March 2011.

[25] EGNOS Open Service: Service Definition Document.

The initial set of EGNOS data access service has been available since 26th July 2012.

At present, EGNOS provides an augmentation for the GPS L1 signal. EGNOS will experience several improvements in the next years, with the objective to transform it into a multi-constellation and multi-frequency augmentation system. EGNOS V3 will augment GPS L1/L5 and Galileo E1/E5 signals by 2025, as shown in Figure 23.

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
EGNOS	GPS L1											
	GPS L5									Full Operational Capability		
	Galileo E1									Full Operational Capability		
	Galileo E5									Full Operational Capability		

Figure 23 – Expected evolution of EGNOS

During January 2018, the availability of the EGNOS open service was above 99%. The horizontal accuracy for all the sites remained below 1.3 meters (95%) and the vertical accuracy remained below 2.5 meters (95%). The offset between the EGNOS Network Time and the GPS time remained below seven nanoseconds over the three previous months[26].

Exploitation strategy

EGNOS has three services: the open service, the safety-of-life service and the EGNOS Data Access Service, EDAS.

The open service and the safety-of-life service are openly available and free of direct user fees.

EDAS is a protected service. EDAS is free of charge, however, users willing to exploit this service need to register.

1.2.2 GBAS

The Ground Based Augmentation System, GBAS, is a local augmentation system for GNSS. Aircraft use it for precision approach operations. GBAS broadcasts pseudo-range corrections for GNSS satellites, from which aircraft can estimate an accurate location. Besides, GBAS gives also a precision approach path, similar to the Instrument Landing System. Knowing its accurate location and the path to follow, aircraft can perform a precision approach and landing.

[26] EGNOS Monthly Performance Report, January 2018

Figure 24 shows GBAS architecture. A series of reference receivers at known locations receive GNSS signals and send them to the control centre. GBAS control centre estimates the error in the pseudo-range for each GNSS satellite in view, together with integrity data. An omnidirectional VHF antenna broadcasts this information, including also the precision approach segment data. Aircraft receive, on the one hand, the GNSS data, and, on the other hand, the GBAS data. Correcting GNSS pseudo-ranges with GBAS data, and following the path provided, they can perform a precision approach and landing.

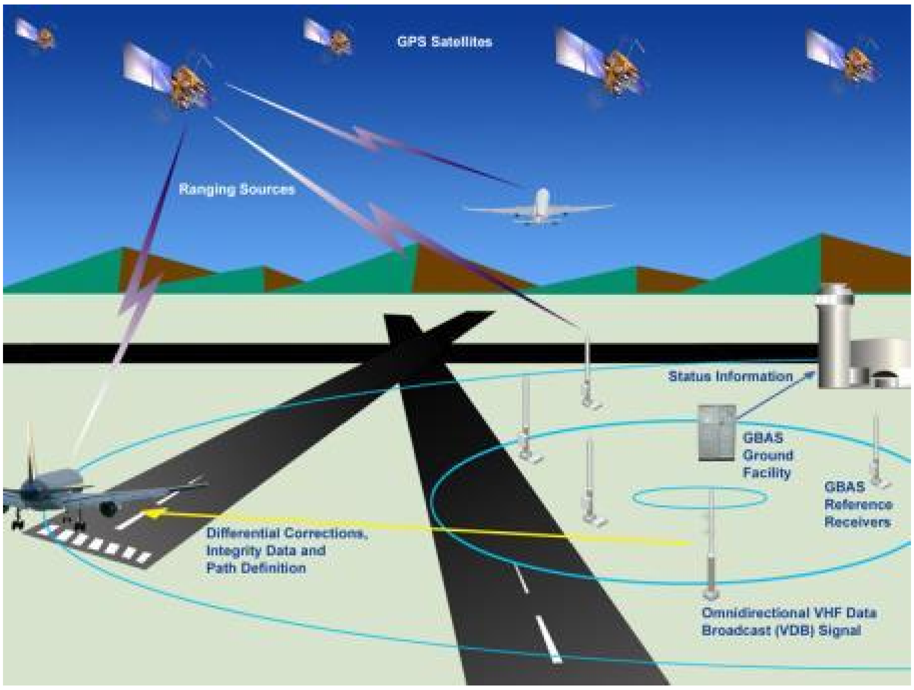
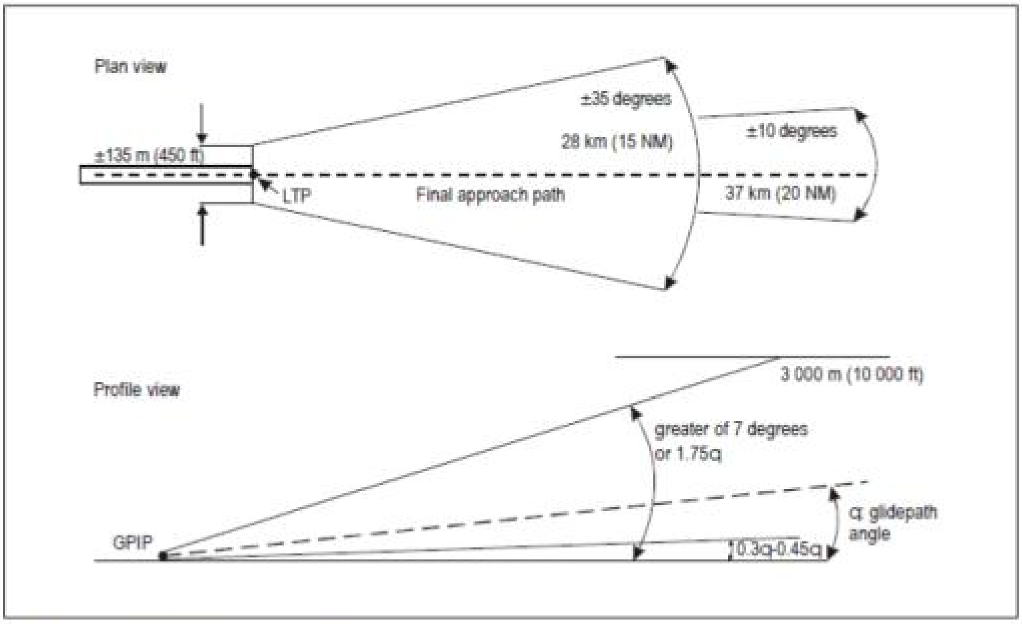


Figure 24 – GBAS architecture (Credit: FAA)

Main characteristics

GBAS ground segment consists of a network of GNSS reference receivers, a control centre, and a VHF Data Broadcast, VDB, and at least a transmitter.

The minimum GBAS coverage, shown in Figure 25, extends horizontally in a sector of ±35° up to 28km from the runway and in a sector of ±10 ° up to 37km from the runway. Vertically, the coverage extends in a cone of at least 7° with origin in the runway up to an altitude of 3000m.



GPIP — glide path intersection point
LTP — landing threshold point

Figure 25 – Minimum GBAS coverage (Credit: ICAO)

GBAS transmits data in the frequency band 108 to 117.975 MHz. Data is transmitted with a D8PSK modulation, at a rate of 10500 symbols per second, with a TDMA technique. Radio signals are either horizontally or elliptically polarised. The navigation data includes pseudo-range corrections, reference time and integrity data, GBAS related data, final approach segment data, and predicted ranging source availability data.

Status and modernisation plans

GBAS Cat I operations based on GPS L1 are already available. GBAS Cat II/III operations based on GPS L1 are expected to be available in 2020. GBAS Cat II/III operations based on GPS L1/L5 and Galileo E1/E5 are expected to be available in 2026, as represented in Figure 26[27]. MultiConstellation and MultiFrequency GBAS will be able to provide the robustness required to support Cat II/III operations in low-latitude regions, which suffer from ionospheric anomalies. Furthermore, MC/MF GBAS provides improved robustness levels in mid-latitude scenarios against full constellation or single frequency losses.

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
GBAS	Cat I (GPS L1)											
	Cat II/III (GPS L1)							Full Operational Capability				
	Cat II/III (GPS-Galileo L1/E1 L5/E5)										Full Operational Cap.	

Figure 26 – Expected GBAS evolution

27 European ATM Master Plan, 2015

Figure 27 shows GBAS operational and research stations currently deployed in Europe (October 2017).

Figure 27 – GBAS stations (Credit: www.flygls.net)

Exploitation strategy

The costs of air traffic management services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges under a "user pays" principle. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all Eurocontrol's Member States.

1.2.3 DGNSS

Differential GNSS, DGNSS, is a ground-based augmentation to satellite navigation systems. Its working principle is similar to EGNOS and GBAS described before. A network of reference stations, located very precisely on ground, monitors the signals transmitted by GNSS satellites and sends them to a control centre. The control centre calculates corrections for the pseudo-ranges of the satellites, together with integrity information. This information is broadcasted to the user, who uses it to correct the pseudo-ranges directly received from the GNSS constellation. As a result, the user can estimate its position with greater accuracy, and gets an alert in case any navigation satellite works below a certain quality threshold. Figure 28 shows the architecture of a DGNSS system.

Figure 28 – DGNSS architecture (Credit: US RNP)

There are several implementations capable of providing a DGNSS service, which differ principally on how the system sends the corrections to the user (radio broadcast, cellular telephony, Internet ...). Access to the service may also change among implementations (free access, registered access, registered plus fee access …).

In developed countries, two implementations of DGNSS are very common: terrestrial and maritime.

Terrestrial DGNSS relies on a network of monitoring stations spread across the country. Access to the service normally employs the mobile cellular network or the Internet. Service can be free or granted after payment of a fee, and can be offered in real time or in post-processing mode. The real time service reaches accuracies in the centimetre range, while the post-processing service reaches accuracies in the millimetre range. As an example, Figure 29 shows the terrestrial DGNSS network of Sweden. Most of the European countries, if not all, have their own DGNSS terrestrial network. Examples include Flepos, Walros and Ignbru (Belgium), Eposa, Apos, NetFocus and Doris (Austria), RGP (France), Swipos (Switzerland), Netpos (Holland) and Sapos and AXIO-Net (Germany).

Figure 29 – SWEPOS network (Credit: SWEPOS website)

The mobile cellular network does not have coverage over the seas. However, for the maritime community, radio beacon DGNSS is the standard way of providing the augmentation information to the users. In this case, the corrections are broadcasted on the maritime radio beacon band from 283.5 to 325 KHz. The transmitting stations are located close to the coast, and provide increased accuracy and integrity information for the coastal and harbour approach phases of navigation. Typical accuracy for radio beacon DGNSS is between 1 and 3 metres, and depends on the distance between the user and the reference stations. Access to the service is free, and users only need a compatible receiver. As an example, Figure 30 shows the maritime DGNSS network of Spain, which provides a 100-nautical-mile coverage parallel to the Spanish coastline.

Figure 30 – Maritime DGNSS in Spain (Credit: www.puertos.es)

The adoption of EGNOS in the maritime sector could constitute and alternative or a complementary system to the maritime DGNSS. For example, the GLA RNP expects a rationalisation of their radio beacon DGNSS system around 2021.

2. Ground-based Systems

2.1 NDB

A Non-Directional Beacon, NDB, is a radio navigation aid that allows an aircraft to know its bearing with respect to it. NDBs are very simple systems, composed of an omnidirectional antenna that continuously broadcasts a carrier signal at a fixed frequency. Aircraft equipped with an Automatic Direction Finder, ADF, can calculate the angle of arrival of that signal, i.e., the bearing to the NDB. Several NDBs can be used to indicate a route. The accuracy of the system depends on the ADF equipment installed on-board aircraft.

Main characteristics

NDBs shall operate in the frequency band from 190 to 1750 KHz, and shall transmit continuously a modulated carrier with identification information. The frequency of the modulating tone shall be 1020 ± 50 Hz or 400 ± 25 Hz. Each NDB shall be individually identified by a code, which will be transmitted at least once every 30 seconds. NDBs shall include a monitor system that detects malfunctioning of the NDB or of the monitor itself[28].

The NDB system has no capacity limitations.

Status and rationalisation plans

NDBs have been part of the ground infrastructure of aids to navigation for air traffic management during decades. However, due to its technical limitations, the appearance of GNSS, and the transformation towards performance-based navigation, we expect NDBs to end operations in the near future. The European ATM Master Plan proposes decommissioning of NDBs by 2020.

ICAO's GANP expects NDBs to become less important as radio navigation aids, with the opportunity to be decommissioned.

Exploitation strategy

The costs of air traffic management services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges under a "user pays" principle. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all Eurocontrol's Member States.

[28] ICAO Annex 10 Volume 1 Radio Navigation Aids

2.2 VOR

The VHF Omnidirectional Radio Range, VOR, is a system that allows aircraft to know its bearing with respect to it. It is composed of a circular array of antennas, which transmits two radio signals. One of the signals is transmitted omnidirectionally. The other signal is very narrow and focused on a specific direction. This direction rotates at 30 revolutions per second. The equipment on-board aircraft receive both signals and, from their phase difference, the bearing with respect to the VOR is estimated. If the VOR is associated with a DME, aircraft can also calculate their slant distance to the VOR. A network of VOR stations on the ground, using triangulation, allows aircraft to know their position and navigate from one point to another.

Main characteristics

The VOR shall operate in the frequency band from 108 to 117.975 MHz, with horizontal polarisation. The accuracy of the bearing information shall be within ±2°. The coverage of the system is limited by the line of sight, up to an elevation of 40°. The VOR shall have a monitoring unit that generates a warning and either removes the navigation content from the carrier or switches off the radiated power if certain conditions of service provision are not met. The same shall happen if the monitor itself fails[29].

The VOR system has no capacity limitations.

Status and rationalisation plans

VORs have been part of the ground infrastructure of aids to navigation for air traffic management during decades. However, due to its technical limitations, the appearance of GNSS, and the transformation towards performance-based navigation, we expect VORs to become less important in the following years. The European ATM Master Plan plans to reduce the number of VORs to a Minimum Operational Network by 2020. This network would provide some limited navigation capabilities in case of a temporary disruption of GNSS.

ICAO's GANP expects VORs to become less important as radio navigation aids, with the opportunity to be decommissioned.

Exploitation strategy

The costs of air traffic management services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges under a "user pays" principle. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all Eurocontrol's Member States.

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[29] ICAO Annex 10 Volume 1 Radio Navigation Aids

2.3 DME

The Distance Measuring Equipment, DME, is a system that provides the slant range distance between an aircraft and the corresponding installation on ground. DMEs are composed of two elements: interrogator and transponder. The interrogator is located on the aircraft, and the transponder is located on the ground. The operation of DMEs is simple. The interrogator broadcasts a radio signal, which the transponder receives and processes. After a specified time, the transponder replies with another radio signal. The round-trip time serves to compute the slant range distance between both equipment.

Main characteristics

The DME shall operate in the frequency band from 960 to 1215 MHz, with vertical polarisation. Normally DMEs are associated with VORs, ILSs or MLSs. If associated with a VOR, DME coverage shall be at least that of the VOR. If associated with an ILS or MLS, DME coverage shall be at least that of the ILS or MLS azimuth angle guidance sectors. The total system error, up to a distance of 370 km, should not be greater than 1.25% of the measured distance ±460 m. The power radiated by the transponder must ensure a peak pulse power density of –89 dBW/m^2 under all weather conditions in the coverage area. The DME transponder shall have a monitoring unit that generates a warning and switches off the radiated power if certain conditions of service provision are not met, or even if the own monitor fails. This shall occur in less than 10 seconds since the beginning of the failure[30].

The DME has a capacity limit of 100 aircraft.

Status and optimisation plans

DMEs are part of the ground infrastructure of aids to navigation for air traffic management. An optimised or even expanded network or DMEs will support performance-based navigation. DMEs might constitute a backup infrastructure in case of GNSS failure. The European ATM Master Plan proposes to optimise the DME network by 2019.

ICAO's GANP identifies DMEs to be an appropriate backup to GNSS for performance-based navigation. To provide a good service in case of a GNSS outage, the network of DMEs might need to expand.

Exploitation strategy

The costs of air traffic management services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges under a "user pays" principle. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all Eurocontrol's Member States.

[30] ICAO Annex 10 Volume 1 Radio Navigation Aids

2.4 ILS

The Instrument Landing System, ILS, is "a radio navigation system that provides aircraft with horizontal and vertical guidance just before and during landing and, at certain fixed points, indicates the distance to the reference point of landing"[31]. It is composed of a localiser, a glide path and marker beacons. The ILS localiser is "a system of horizontal guidance embodied in the ILS which indicates the horizontal deviation of the aircraft from its optimum path of descent along the axis of the runway"[32]. The ILS glide path is "a system of vertical guidance embodied in the instrument landing system which indicates the vertical deviation of the aircraft from its optimum path of descent"[33]. A marker beacon is "a transmitter in the aeronautical radio navigation service which radiates vertically a distinctive pattern for providing position information to aircraft"[34].

The ILS localiser, shown in Figure 31, transmits two radio beams, with different modulations, that intersect in the runway centre line. It provides azimuth information to aircraft.

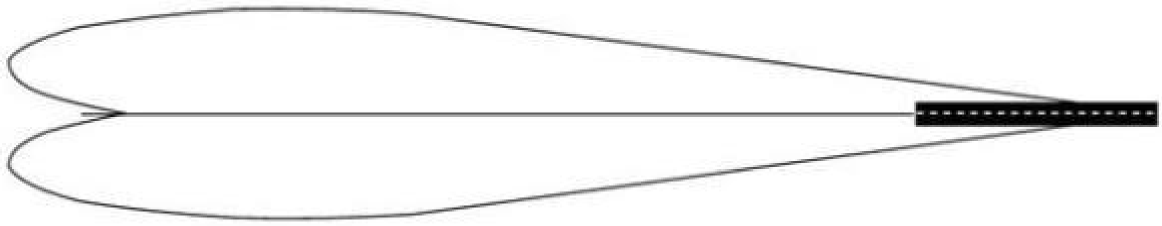

Figure 31 – ILS localiser radio beams (Credit: SKYbrary)

Similarly, the ILS glide path transmits two radio beams, with different modulations, that intersect in the optimum descent path. It provides vertical information to aircraft. The marker beacons are situated at specific points from the runway, and provide to aircraft the distance missing until the runway. Figure 32 shows ILS glide path and marker beacons. Using the three elements, aircraft know their horizontal deviation with respect to the centre of the runway, their vertical deviation with respect to the optimum descent path, and their distance to the runway.

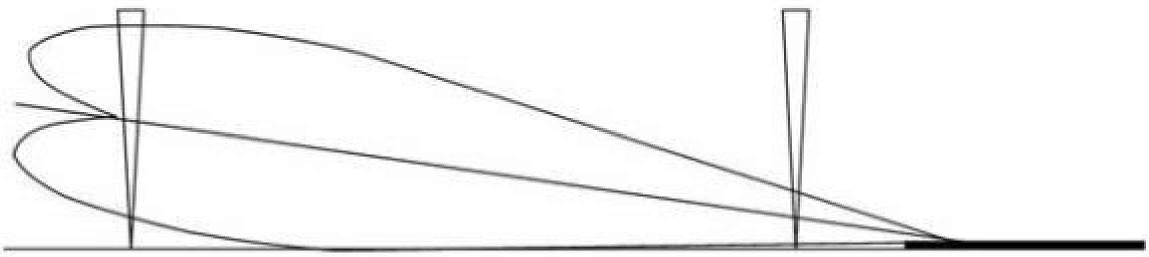

Figure 32 – ILS glide path and marker beacons radio beams (Credit: SKYbrary)

31 ITU Radio Regulations. Edition of 2012. Article 1.104

32 ITU Radio Regulations. Edition of 2012. Article 1.105

33 ITU Radio Regulations. Edition of 2012. Article 1.106

34 ITU Radio Regulations. Edition of 2012. Article 1.107

Main characteristics

We summarise below the principal specifications of the ILS system. For the full specifications set, consult ICAO Annex 10 Volume 1 Radio Navigation Aids.

The ILS shall comprise a VHF localiser, a UHF glide path and VHF marker beacons.

The localiser shall operate in the band 108 – 111.975 MHz. The signals broadcast are modulated in AM with a 90 Hz and 150 Hz tone, with each tone predominating in one side of the course, and horizontally polarised. The localiser coverage shall extend from the centre of the antenna to distances of:

- 46.3 km within ± 10° from the front course line
- 31.5 km between 10° and 35° from the front course line
- 18.5 km outside of ±35° if coverage is provided.

The field strength shall not be less than 40 µv/m. The course alignment accuracy shall be maintained within the following limits:

- For Cat I localisers. ±10.5 m or the linear equivalent of 0.015 DDM, whichever is less
- For Cat II localisers. ±7.5 m
- For Cat III localisers. ±3m

An automatic monitor system shall provide a warning and even the shutdown of the emission if certain conditions of provision of the service are not met. Integrity shall be greater than $1 - 0.5x10^{-9}$ for Cat II/III localisers, and greater than $1 – 1.0x10^{-7}$ for Cat I localisers. Continuity of service shall be greater than:

- $1 – 4x10^{-6}$ in any period of 15 seconds for Cat I localisers
- $1 – 2x10^{-6}$ in any period of 15 seconds for Cat II localisers
- $1 – 2x10^{-6}$ in any period of 30 seconds for Cat III localisers

The glide path equipment shall operate in the band 328.6 – 335.4 MHz. The radiation is amplitude modulated by a 90 Hz and 150 Hz tone and horizontally polarised. The glide path coverage shall extend in sectors of 8° in azimuth on each side of the centre line of the ILS glide path, to a distance of at least 18.5 km. The minimum field strength shall be 400 µv/m. An automatic monitor system shall provide a warning and the shutdown of the emission if certain conditions of provision of the service are not met. Integrity shall be greater than $1 - 0.5x10^{-9}$ for Cat II/III facilities, and greater than $1 – 1.0x10^{-7}$ for Cat I facilities. Continuity of service shall be greater than:

- $1 – 4x10^{-6}$ in any period of 15 seconds for Cat I equipment.
- $1 – 2x10^{-6}$ in any period of 15 seconds for Cat II/III equipment

The marker beacons shall operate at 75 MHz and their signals horizontally polarised. There shall be two marker beacons in each installation to indicate predetermined distance, and a third one if considered by the competent authority. The field strength shall be 1.5 mv/m at the limit of the coverage, and shall rise to at least 3.0 mv/m within the coverage area. The modulation frequencies shall be:

- Inner marker. 3000 Hz.
- Middle marker. 1300 Hz.
- Outer marker. 400 Hz.

The marker beacons shall be located at the following distances:

- Inner marker. Between 75 and 450 m from the landing threshold.
- Middle marker. At 1050±150m from the landing threshold.
- Outer marker. At 7.2 km from the landing threshold or, when this is not possible, between 6.5 and 11.1 km from the threshold.

In some ILS installations, VHF marker beacons are being replaced by DMEs co-located with the ILS, which give the pilot continuous horizontal distance to the runway.

An automatic monitor shall transmit a warning if it detects a failure of the system.

The ILS has no capacity limitations.

Status and optimisation plans

The ILS is the most expanded system for precision approach and landing. In recent years, the introduction of ground-based augmentation systems has allowed GBAS Cat I operations. We expect GBAS Cat II/III to start in the near future. Consequently, there will be an opportunity to rationalise the ILS infrastructure. The European ATM Master Plan proposes to rationalise the ILS network by 2020.

ICAO's GANP identifies the ILS as an appropriate backup to GNSS for precision approach and landing, and recommends retaining the current infrastructure.

Exploitation strategy

The costs of air traffic management services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges under a "user pays" principle. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all Eurocontrol's Member States.

2.5 MLS

The Microwave Landing System, MLS, is a precision approach and landing system designed to replace the ILS. It gives azimuth, elevation, ranging and data information to aircraft. It works by means of a scanning radio beam in the coverage area from which the aircraft can estimate their position. It has a wider coverage area than the ILS, allowing for more flexible approach routes. It has also a back azimuth coverage area, giving information to those aircraft that have to abort landing. Ranging information between the runway and the aircraft is given by means of a DME.

Main characteristics

We summarise below the principal specifications of the MLS system. For the full specifications set, consult ICAO Annex 10 Volume 1 Radio Navigation Aids.

The basic MLS shall comprise an approach azimuth equipment, an approach elevation equipment, a data transmission equipment and a DME.

The MLS angle and data equipment shall operate in the band 5030.4 to 5150.0 MHz. The DME equipment shall operate in its specific frequency band. All ground equipment transmissions shall have vertical polarisation. Angle and data information shall be transmitted using time-division-multiplex organisation on a single radio frequency channel.

The approach azimuth ground equipment shall have the following coverage in the approach region:

- Laterally within a sector of 80°.
- Longitudinally to a distance of 41.7 km.
- Vertically up to a surface inclined at 15° until a height of 6000 m.

The back azimuth ground equipment shall have the following coverage:

- Horizontally within a sector of ±20° about the runway centre line, extending at least 18.5 km in the direction of the missed approach.
- Vertically in the runway region up to a surface inclined at 20° until a height of 600 m.
- Vertically in the back azimuth region up to a surface inclined at 15° until a height of 3000 m.

The approach and back azimuth equipment shall have a monitor system that generates a warning and ceases radiation in case certain conditions are not met, or even if the monitor system fails. Integrity for MLS azimuth equipment shall be greater than $1 - 0.5x10^{-9}$ for Cat II/III facilities, and greater than $1 – 1.0x10^{-7}$ for Cat I facilities. Continuity of service for MLS azimuth equipment shall be greater than:

- $1 – 4x10^{-6}$ in any period of 15 seconds for Cat I operations.
- $1 – 2x10^{-6}$ in any period of 15 seconds for Cat II/IIIA operations.
- $1 – 2x10^{-6}$ in any period of 30 seconds for the full range of Cat III operations.

The approach elevation ground equipment shall have the following coverage in the approach region:

- Laterally, within a sector that has an angular extent at least equal to the proportional guidance sector at the longitudinal coverage limit.
- Longitudinally to a distance of 37 km.
- Vertically up to a surface inclined at 7.5°until a height of 6000 m.

The approach elevation equipment shall have a monitor system that generates a warning and ceases radiation in case certain conditions are not met, or even if the monitor system fails. Integrity for MLS approach elevation equipment shall be greater than $1 - 0.5x10^{-9}$ for Cat II/III facilities, and greater than $1 – 1.0x10^{-7}$ for Cat I facilities. Continuity of service for MLS approach elevation equipment shall be greater than:

- $1 – 4x10^{-6}$ in any period of 15 seconds for Cat I equipment.
- $1 – 2x10^{-6}$ in any period of 15 seconds for Cat II/III equipment

DME shall be provided at least throughout the coverage volume in which approach and back azimuth guidance is available.

Status and rationalisation plans

The MLS was designed to be the evolution of the ILS, although it never reached a deployment status to play that role. The introduction of GBAS Cat I, and, in the future, GBAS Cat II/III, means that probably the MLS will never have an extended use. The European ATM Master Plan proposes to rationalise the MLS network by 2020.

ICAO's GANP identifies the MLS as an appropriate backup to GNSS for precision approach and landing, and recommends retaining the infrastructure currently deployed.

Exploitation strategy

The costs of air traffic management services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges under a "user pays" principle. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all Eurocontrol's Member States.

Figure 33 shows the expected evolution of conventional aids to navigation in the civil aviation sector. Several systems will have the opportunity to be rationalised or decommissioned in the next decade.

This is a consequence of the successful deployment and ramp up of GNSS and their satellite and ground-based augmentations. Two important consequences of this infrastructure rationalisation are operational cost savings and release of the spectrum bands occupied by those radio navigation systems. However, to cope with a potential outage of GNSS in critical systems, backups will be needed. In the civil aviation domain, the proposed back up will consist of a minimum operational network of VORs and an optimised network of DMEs. For precision approach and landing, the backup will consist on ILS or MLS.

We have to note that the evolution plans presented here are those envisaged by the international associations that regulate civil aviation, mainly ICAO and the SESAR Joint Undertaking. However, the conventional aids to navigation infrastructure is ultimately responsibility of the different national authorities. These may have policies and plans that differ from those dictated by international bodies, i.e., each member state in the European Union may have its own plan for rationalizing or decommissioning infrastructures.

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
ILS	**Full Operational Capability**					**Rationalize**						
MLS	**Full Operational Capability**					**Rationalize**						
DME	**Full Operational Capability**				**Optimize**							
VOR	**Rationalize**					**Minimum Operational Network**						
NDB	**Rationalize**					**Decommission**						
A-PNT	Research											

Figure 33 – Expected evolution of conventional aids to navigation in civil aviation

With respect to long-term reversionary solutions, the SESAR Joint Undertaking considers a multitude of new technologies that could be introduced to enhance or even replace DMEs and VORs. These Alternative Positioning, Navigation and Timing technologies, A-PNT, include Enhanced DME, Mosaic/DME, LDACS-NAV, eLoran, Wide Area Multilateration/TIS-B, pseudolites, Mode-N and inertial systems. According to the European ATM Master Plan, these A-PNT solutions are still under research, with the entry into service expected not before 2029. Consequently, they will not be treated with further detail in the present edition of the ERNP.

2.6 Loran-C / Chayka

Loran is a hyperbolic navigation system, initially developed in the 1950s. It works by comparing the time of arrival of signals coming from pairs of synchronised transmitters. Receiving the signals from one pair of transmitters, and knowing their positions, the user can restrict its position within a hyperbolic line. Reception of the signals from two additional pair of transmitters restricts the position to a second and a third hyperbolic line. The intersection of the hyperbolic lines marks the position of the receiver. Chayka is a Russian system almost identical to Loran. Receivers are typically compatible with both navigation systems.

Main characteristics

Loran-C[35] operates in the frequency band 90 – 110 KHz, with a power output ranging between 100 kilowatts up to several megawatts. Loran-C transmitters are grouped in chains. Each chain has a master station and, at least, two secondary stations. The master station transmits nine pulses at predefined intervals. Each secondary station, after receiving these pulses, waits a specific delay and transmits eight pulses. The pulses are codified so the receiver can identify the different emissions. The location of the master and the secondary stations, the repetition interval of the master, and the secondary transmission delays are all known. Thus, when a user receives all these pulses, it can estimate the propagation time between its position and the different stations. From this information, it is possible to estimate receiver location. Figure 34 shows the signal structure of a Loran-C chain with one master and two secondary stations.

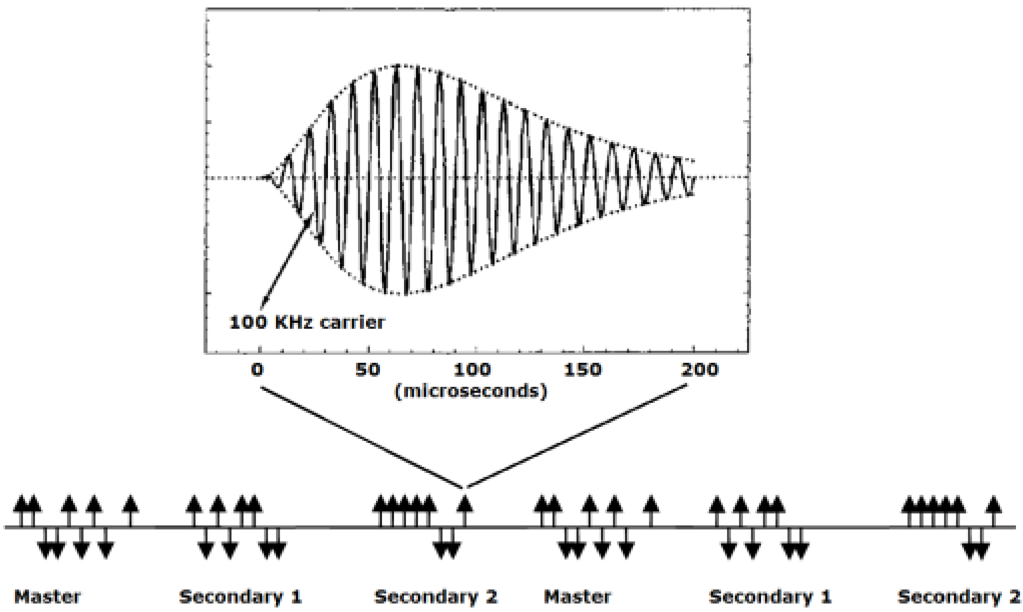

Figure 34 – Loran-C signal structure (Credit: International Loran Association)

[35] Different evolutions of the Loran system receive different names (LORAN, Loran-A, Loran-B, Loran-C). Loran-C was the most recent extended version.

The transmission of very low frequencies at very high powers needs transmission antenna masts that are a few hundred meter-tall. The radiation pattern of these antennas is omnidirectional. Loran-C transmissions need to be accurately synchronised. To do so, each transmitter includes up to three atomic clocks.

Loran-C has an accuracy better than 460 metres, and an availability of 99.7%[36]. Each transmitter has a typical coverage of up to several hundred kilometres. The coverage depends on factors like day/night conditions, weather, and transmission over land or sea. Europe had several Loran-C stations, which provided the coverage presented in Figure 35.

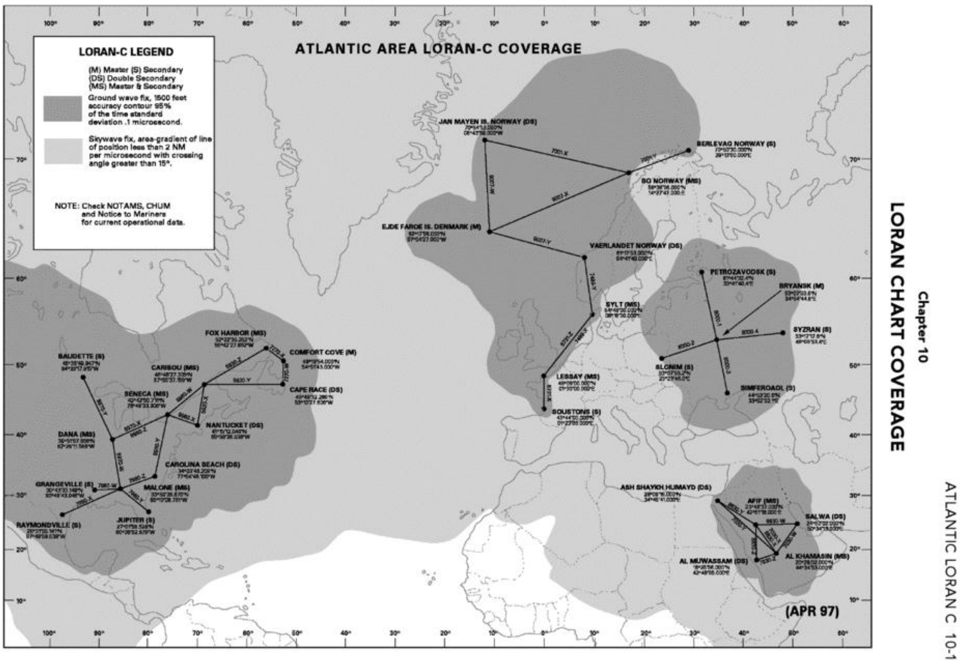

Figure 35 – Atlantic area Loran-C coverage (Credit: Department of Defence General Planning 2006)

Loran-C has no capacity limitations.

Status and rationalisation plans

The development of satellite navigation systems reduced strongly the number of Loran-C users. France, Norway, Denmark, and Germany terminated their Loran-C transmissions in 2015.

[36] US FRP 2008

2.7 eLoran

The International Loran Association published in 2007 a definition document for an Enhanced Loran, eLoran, system[37]. The US Coast Guard led this effort, together with the GLA of the UK and Ireland, the US FAA, DCN Brest (France Ministry of Defence), and several independent consultants.

Main characteristics

eLoran uses state-of the art technology to provide a Loran-type service with higher accuracy, availability and integrity. The main difference between both systems is the addition in eLoran of a data channel, transmitted together with the Loran signal. This data channel serves to transmit corrections and integrity information, which enhances the performance with respect to the basic Loran system. The data channel also transmits timing information.

The eLoran system is composed of transmitting stations, monitoring sites and a control centre, as indicated in Figure 36. Monitoring sites check the timing accuracy of the transmitted signals, and send corrections to the control centre when needed. The control centre collects the observations from the monitoring stations, processes them and produces the correction and integrity data to be broadcasted by the transmitting stations. These stations transmit the corrections using the data channel. The result is a system with increased accuracy, integrity, availability and continuity than Loran-C.

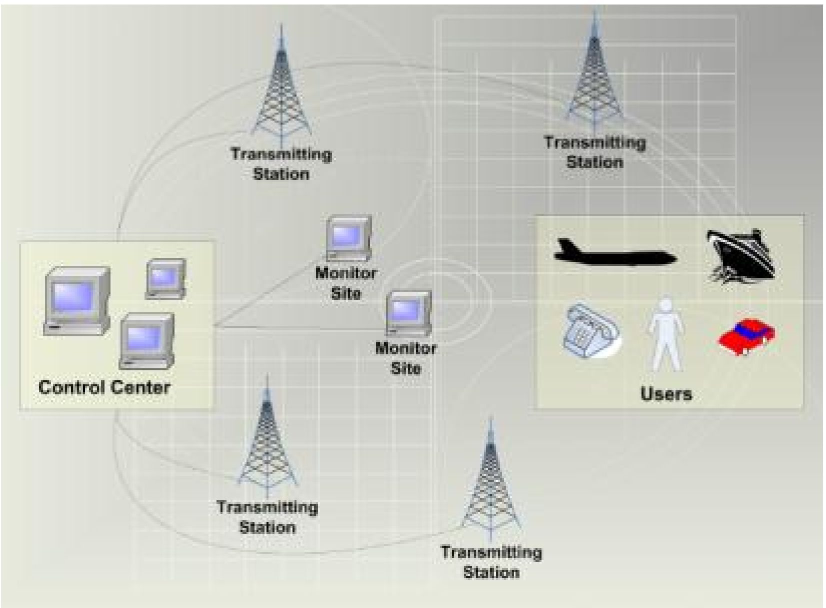

Figure 36 – eLoran system (Credit: eLoran Definition Document)

Table 11 summarises the performance of eLoran.

37 International Loran Association. Enhanced Loran (eLoran) Definition document. 16 October 2007.

Table 11 – eLoran performance

Position Accuracy	**Time Accuracy**	**Frequency Accuracy**	**Availability**	**Integrity**	**Continuity**
8 – 20 m	50 ns	Stratum 1 (1×10^{-11})	0.999 – 0.9999	0.999999 (1×10^{-7})	0.999 – 0.9999 over 150 seconds

eLoran transmitting stations are equipped with atomic clocks, and transmissions are precisely synchronised to UTC. Consequently, the system is completely independent from GNSS, and may provide a backup solution in the case of a disruption of GNSS services.

The coverage of eLoran is the same as the coverage of Loran-C. The working principle of Loran-C and eLoran is the same, so signals from at least three transmitting stations are needed to locate a receiver. Timing information does not need triangulation, so one transmitting station is enough.

eLoran has some advantages over GNSS. First, signals are transmitted with very high power and at a very low frequency. The transmission of these signals needs complex infrastructure, including antennas that can be up to 200 metres high. Given the high transmit power of the eLoran stations, jamming eLoran receivers becomes very difficult to do without being detected. Second, the low frequency used (around 100 KHz, the same as Loran-C) penetrates buildings and other areas where GNSS signals are not available. Thus, position and timing services from eLoran would be available in these difficult indoor environments and in urban canyons. One must however note that the positioning and timing accuracies provided by eLoran can vary significantly within the coverage area and are poorer than those available from GNSS.

Status and modernisation plans

The GLA announced in December 2015 the discontinuation of its eLoran prototype service[38] in the UK and Ireland. Following France and Norway plans to stop their Loran transmissions, the GLA realised its eLoran service would not provide positioning and navigation capabilities to their users.

[38] https://www.nlb.org.uk/Navigation/NoticeToMariners/Documents/DISCONTINUATION-OF-GLA-ENHANCED-LORAN-(ELORAN)-INITIAL-OPERATIONAL-CAPABILITY-(IOC)-PROTOTYPE/TRIAL-SERVICE/

2.8 Differential eLoran

Differential eLoran, eDLoran, is a local augmentation system that enhances the performance of eLoran on a specific area.

Main characteristics

The working principle is similar to DGNSS. Under the area of interest, several eDLoran reference stations are deployed. Those stations, whose exact position is known, include an eLoran receiver and a communication link to an eDLoran control centre. The reference stations use eLoran to estimate their positions, and send this information to the eDLoran control centre, which calculates the errors with respect to the actual positions. Thus, the control centre knows the performance of eLoran in the area of interest, and calculates differential corrections for the coverage area.

A user of eDLoran needs an eLoran receiver and a wireless communication link to the eDLoran control centre. The user gets his position with eLoran and sends it to the eDLoran control centre. The control centre calculates the optimum differential corrections for that position, and sends it back to the user. Finally, the user applies those corrections and gets an improved PNT information. The communication link between users and the eDLoran control centre employs the public mobile telephone network (3G/4G).

eDLoran infrastructure (reference stations and control centre) is independent from the eLoran system.

Dynamic tests performed in the harbour of Rotterdam showed an accuracy of eDLoran better than ±5 metres.

Status and modernisation plans

eDLoran is a local augmentation system to eLoran. Since Loran-C and eLoran transmissions ceased in Europe in 2015, eDLoran services are not possible any more.

2.9 Longwave time and frequency distribution systems

Longwave systems (e.g. DCF77 in Germany, MSF in United Kingdom and TDF in France) have been used in Europe to distribute legal time and standard frequency for decades. They employ very low frequencies and high power to reach distances up to thousands of kilometres. We describe below the characteristics of the DCF77 system.

DCF77 is one of the methods used by PTB to disseminate the legal time and frequency standard in Germany[39]. It uses three atomic clocks to generate a carrier frequency of 77.5 KHz. An omnidirectional 150-metre high antenna transmits the signal at an equivalent isotropic radiated power of 35 KW. The antenna is located in Mainflingen, and provides coverage to most parts of Europe, as shown in Figure 37.

Figure 37 – DCF77 coverage (Credit: PTB)

The carrier is modulated in amplitude to transmit the time and date information, as shown in Figure 38. Every second, the carrier's amplitude is reduced to a 15% of its original value. A binary '0' is transmitted if the reduction in amplitude lasts 0.1 seconds. A binary '1' is transmitted if the reduction in amplitude lasts 0.2 seconds. Thus, the system is able to transmit 60 bits per minute. Figure 39 shows the code employed for this transmission. Bits 21 to 27 codify the minute, bits 29 to 34 codify the hour, bits 36 to 41 codify the day of the month, bits 42 to 44 codify the day of the week (Monday is day 1), bits 45 to 49 codify the month of the year and bits 50 to 57 codify the year. There are, additionally, several parity bits, and other control bits to inform about the time zone, and the introduction of leap seconds. Bit 59 is not modulated in amplitude, indicating that a new minute starts with the following bit, and serves for synchronization of the receivers.

39 The legal time is also distributed by the public telephone network and by Internet.

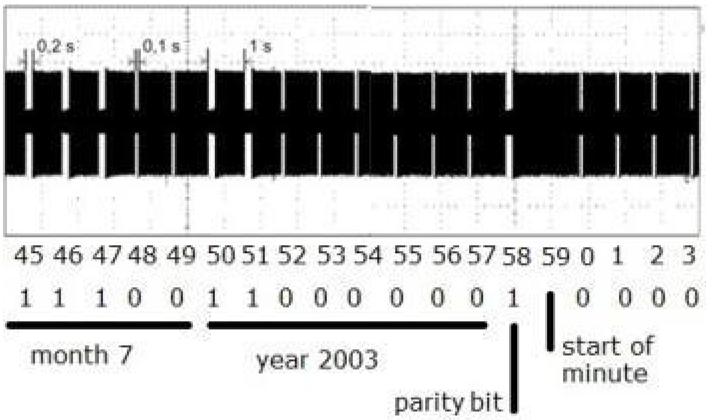

Figure 38 – DCF77 amplitude modulation (Credit: PTB)

The 60 bits are transmitted every minute, i.e., the user receives every minute information regarding the year, the month, the day of the week, the day of the month, the hour and the minute. The second is obtained counting how many reductions in amplitude have occurred since the start of the minute.

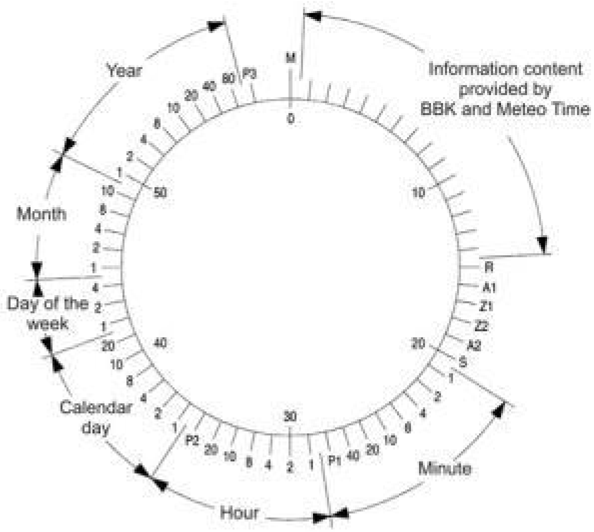

Figure 39 – DCF77 time code (Credit: PTB)

The carrier frequency has an average deviation of less than $2x10^{-12}$ on one day at the place of transmission. The zero crossing of the carrier signal is maintained to within 5.5±0.3 microseconds with respect to the UTC realization at PTB.

DCF77 entered into operation in 1959 and the existing contractual regulation extends until 2021. DCF77 is used to synchronize time keeping systems in German train stations, by TV and radio broadcast companies, in the energy and telecommunication industries, to calibrate frequency generators, and by private individuals in possession of radio-controlled clocks. An advantage of DCF77 over GNSS is its ability to penetrate inside buildings and in difficult environments. We expect the continuation of DCF77 after the present contract expires in 2021. The availability of DCF77 in 2016 was 99.79%, excluding disconnections of less than two minutes.

2.10 Emerging positioning and timing services.

2.10.1 Cellular networks based positioning

At present, a majority of personal communication devices, like smartphones and tablets, integrate a GNSS receiver, which gives precise location information. However, there are several environments where GNSS devices cannot operate, or where there performance is severely degraded: urban canyons, indoors, tunnels, or underground. In these situations, the own cellular communication network can provide positioning information to their users. There are several methods to do this. The simplest one is by cell identification. Knowing which base station serves the cell phone, knowing the location of the base station and knowing its coverage area, it is possible to locate the cell phone within that area. The accuracy of the method, however, is limited to the cell's size, which can be quite large in rural areas. It is possible to improve the performance of this method by estimating the distance between the cell phone and the base station (which can be done, for example, measuring the received power of a pilot signal). However, the positioning is still limited to an area around the base station.

Similarly to GNSS, it is possible to measure the distance to different base stations to get a better solution. Measuring the distances to three adjacent base stations, the positioning would be limited to a point. In this case, the accuracy would depend on the uncertainties in the estimated distances to the base stations. Instead of the distances, it is also possible to estimate the position of the cell phone measuring the angle of arrival of the signals. In good geometry conditions, with signals arriving at close to right angles, two measurements would be enough to get a solution.

LTE networks also support positioning based on observed time difference of arrival of pilot signals. The difference in time of arrival to the cell phone of a signal transmitted by two base stations defines a hyperbola where the phone is located. Measuring this for three different pairs of base stations, three hyperbolas can be calculated. The three hyperbolas intersect in one point, which marks the position of the user. This method is conceptually equivalent to the Loran-C system described before.

Figure 40 shows the LTE positioning architecture. There are three main elements in this architecture: a location services client (LCS client), a location services target (the terminal), and a location services server (E-SMLC or SLP). The positioning process starts when a LCS client sends a request to get the position of a terminal. The location services server processes the request, collects the measurements taken between the terminal and the base stations, and estimates the position of the terminal. Finally, it sends the estimated position to the LCS client that originated the request. There are two interesting features on this architecture. First, the positioning of the terminal is estimated by the network, and not by the terminal itself. Second, the positioning request originates and finalises in the LCS client, which may correspond to the terminal device or not.

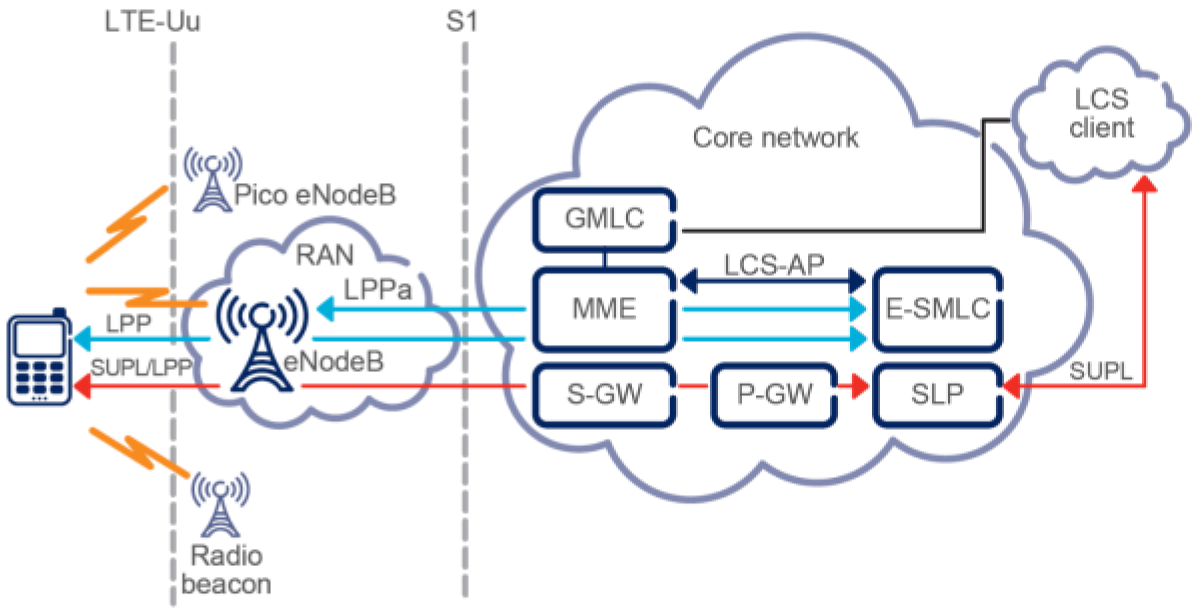

Figure 40 – LTE positioning architecture (Credit: Ericsson)

LTE positioning presents advantages but also disadvantages over GNSS. As already mentioned, LTE positioning works in certain environments where GNSS has problems, like inside buildings, urban canyons or underground. LTE positioning accuracy strongly depends on the size of the cell. It is better in urban areas, where cell density is elevated and cells are small, than in rural ones. However, even in the best situation, GNSS performance is superior to LTE positioning. The development of new communication standards, with smaller cells and higher frequencies will increase the accuracy of LTE positioning. Another limitation is the fact that most base stations are located close to the ground, so no vertical information, or very limited one, can be obtained using LTE positioning. Consequently, this technology could have important limitations in new markets under development, like drones. Finally, LTE does not have global coverage over the whole Earth, but only on those areas where LTE networks are deployed.

As previously described, the accuracy of LTE positioning depends on the size of the cell. The best performance is achieved in urban environments, and ranges in the scale of tens of metres. Thus, at present, LTE cannot compete with the accuracy of GNSS. However, a hybrid LTE-GNSS solution could be interesting for those areas where GNSS reception is degraded or unavailable, or for obtaining an initial fix.

The evolution of mobile communication networks, with smaller cells, higher data rates, and higher frequencies, will bring an increase in the accuracy of the positioning solution. The standards of 5G are currently under development. A revolutionary concept of 5G is the possibility of stablishing device-to-device communications. This will allow the concept of cooperative positioning. There are studies that claim that 5G cooperative positioning could have accuracies in the sub-metre range. The first 5G networks in Europe are expected to be operative around year 2020.

2.10.2 Iridium Satelles Time and Location

In 2016, a consortium formed by Iridium, Satelles and Boeing presented Satelles Time and Location, STL, a new global navigation satellite system. The systems employs Iridium LEO constellation of 66 satellites, having global coverage over the Earth. STL has several differences over traditional GNSS.

A communication constellation, like Iridium, is, in principle, designed to have just one satellite in the user's field of view. When that satellite moves over the horizon, another one comes, giving continuity to the communication. STL uses the motion of the satellite to provide a positioning solution employing only one satellite, instead of the four needed in classical GNSS. Each of the 66 Iridium satellites has 48 spot beams. To provide secure and anti-spoofing capabilities, each beam transmits the navigation message with an individual code, which changes every second. Actually, the navigation message can be sent only to those areas where there are subscribers of the service, avoiding an unnecessary waste of power. Iridium satellites are about 25 times closer than GNSS ones, so the received power on Earth's surface is much stronger. This allows STL reception in areas where typically GNSS is degraded, like indoors. The satellites do not carry atomic clocks on-board. Instead, they are constantly calibrated using ground station and the inter-satellite capabilities of the Iridium constellation. Subscribers need to pay a service fee.

Figure 41 shows the horizontal error of STL as a function of time. As explained before, the system employs the motion of the satellites to get user position. Therefore, when turning it on, it needs some time to offer a good solution. After 15 minutes of operation, the horizontal accuracy is approximately 50 metres with a confidence level of 90%. Timing accuracy is on the order of hundreds of nanoseconds.

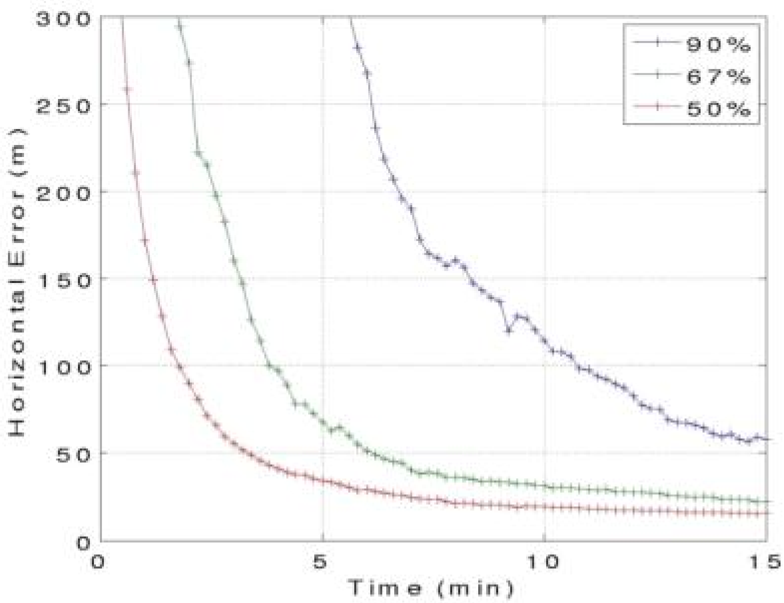

Figure 41 – Iridium-Satelles Time and Location System Horizontal Error (Credit: Satelles)

We have to note that, at present, STL is not independent from GPS, since it uses internally GPS to synchronize its operation. However, the company claims that it will eliminate this dependence.

As in the case of LTE positioning, the basic accuracy of STL cannot compete with GNSS. However, a hybrid STL-GNSS solution could be interesting for those areas where GNSS reception is degraded or unavailable. In those areas, however, STL would need to compete with LTE, which provides similar accuracies without a service fee. The commercial success of STL will probably determine its future evolution. Thus, at this time, it is not possible to assess the availability of the service in the coming years.

Figure 42 shows the expected evolution of other terrestrial and emerging PNT systems. Loran-C, eLoran and eDLoran were switched off in Europe in 2015. DCF77 is available, with contracts signed until 2021 and expectations that it will continue afterwards. Positioning based on 4G networks is available. Initial operations of 5G networks are expected for 2021. STL started operations in 2016. The evolution of this service is uncertain, as it will depend on a private company decision.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Loran-C	Turned off										
eLoran	Turned off										
eDLoran	Turned off										
DCF77	**Full Operational Capability (contract signed until 2021)**										
LTE	**Full Operational Capability (4G). Initial operations in 5G expected for 2020**										
STL	Start of operations in 2016. Continuation of service will depend on company decision										

Figure 42 – Expected evolution of other terrestrial and emerging systems

ANNEX 2. End-User Requirements

Annex 2 presents a review of positioning and timing requirements for the following user groups or sectors:

- Civil aviation.
- Maritime and inland waterways navigation.
- Road transport.
- Agriculture.
- Mapping and Surveying.
- Location-Based Services.
- Rail transport.
- Space users.
- Precise Timing and Synchronisation.
- Emerging applications.

We provide a brief description of the user requirements, the economic impact and forecasted evolution of each particular sector. These elements are very relevant to understand how the mix of radio navigation systems is expected to evolve in the coming years. This evolution will also depend on the development of new emerging applications. One clear example is the sector of autonomous and remotely controlled vehicles, which is currently very active. During the last years, this sector has experienced a period of exponential growth, and we expect it will continue to do so in the near future. We provide a longer review of these emerging applications, with examples of stat-of-the-art systems currently under development worldwide.

The end user requirements tables presented on this Annex are based on published requirements by different stakeholders and do not aim to be exhaustive. The GSA is ongoing a specific activity to consolidate and publish user requirements per market segment. The first User Consultation Platform of the Galileo Program, organised by the European Commission and the GSA, was held in November 2017. It aims to publish in early 2018 the user requirements reviewed by a large community of users and experts. The user requirements output of this activity will be included in the next edition of the ERNP. The end user requirements tables specify the parameters used to characterize GNSS performance:

- Accuracy. The difference between the estimated position or velocity and the real one.
- Availability. The percentage of time that a navigation system is usable.
- Integrity. It is a measure of the correctness of the information provided by a navigation system.
- Continuity. The probability that a navigation system will be usable for the duration of a specific operation, providing it was usable at the beginning of the operation. It gives an estimation of the probability that the navigation system fails in the middle of an operation that has already started.

- Time to alert. The maximum time allowed between a failure in a navigation system and the notification to its users.

1. Civil Aviation

Air transport has an annual worldwide impact of about 2 trillion euro to global Gross Domestic Product, supports 56.6 million direct and indirect jobs, and carries annually more than 2900 million passengers and about 5 trillion euro in cargo. Air traffic has doubled in size every 15 years since 1977, despite economic cycles, and it is expected to do so in the future[40].

Figure 43 shows the historical record of flights in Europe, and a 20-year forecast. At present, there are slightly less than 10 million flights in Europe annually. In 2035, this figure will rise to about 14.4 million[41].

GNSS-enabled economy is the share of the sectoral economy supported, enabled and influenced by the usage of GNSS technology. GNSS-enabled economy in the European air transport sector accounts for 95000 million euro. GNSS indirect impact is the sum of the cost savings and productivity increases allowed by the usage of GNSS systems. GNSS indirect impact in the air transport sector ranges between 737 and 931 million euro[42].

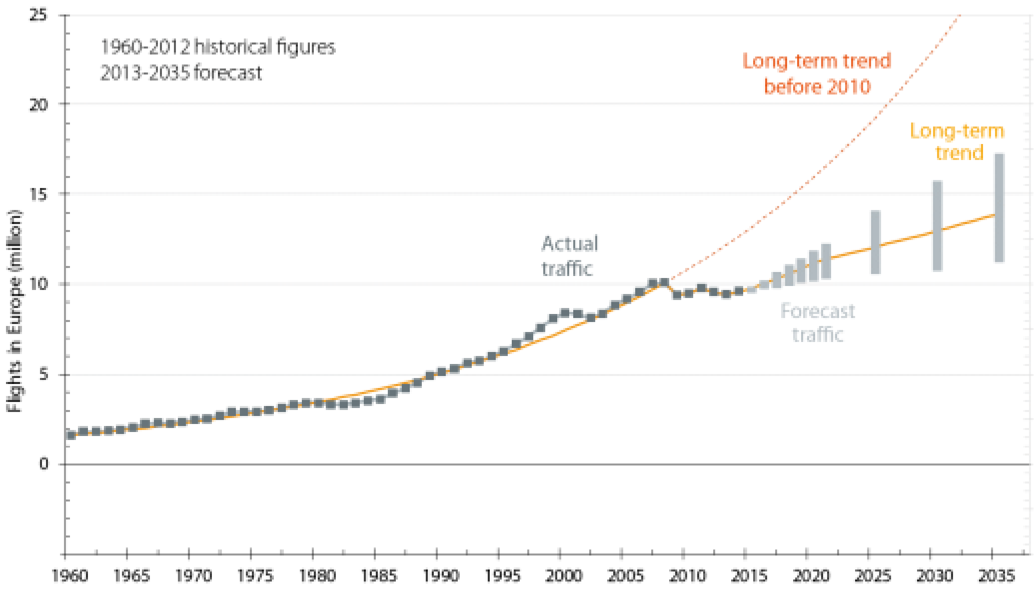

Figure 43 – Number of flights in Europe (Credit: SESAR)

A typical flight consists on a series of consecutive phases, from take-off to landing, as Figure 44 shows. During each phase, aircraft complete a different mission, and have different requirements of

40 ICAO GANP 2013

41 European ATM Master Plan 2015

42 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

operation. Take-off starts with the application of take-off power and finishes at an altitude of 35 feet above runway elevation. En-route comprises from completion of initial climb through cruise altitude until completion of controlled descent to the initial approach fix. Approach starts at the initial approach fix and finishes at the beginning of the landing flare. Landing goes from the beginning of the landing flare until aircraft exits the landing runway.

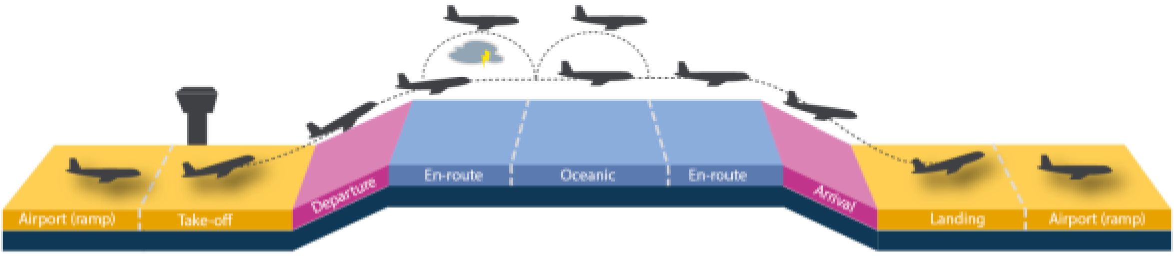

Figure 44 – Phases of flight (Credit: SESAR)

Navigation requirements depend, among other factors, on the different phases of flight. Table 12 summarises those requirements.

Table 12 – Requirements for the different phases of flight[43,44,45]

Phase	Horizontal accuracy ------------ Horizontal alert limit	Vertical accuracy ----------- Vertical alert limit	Integrity	Time to alert	Continuity	Availability
Oceanic	18.5 or 7.4 Km ------------- 7.4 Km	N/A ----------- N/A	$1\text{-}1\text{x}10^{-7}$/h	N/A	N/A	0.99 to 0.99999
En-route	3.7 Km ------------- 7.4 or 3.7 Km	N/A ----------- N/A	$1\text{-}1\text{x}10^{-7}$/h	5 min	$1\text{-}1\text{x}10^{-4}$/h to $1\text{-}1\text{x}10^{-8}$/h	0.99 to 0.99999
Terminal	0.74 Km ------------- 1.85 Km	N/A ----------- N/A	$1\text{-}1\text{x}10^{-7}$/h	15 s	$1\text{-}1\text{x}10^{-4}$/h to $1\text{-}1\text{x}10^{-8}$/h	0.99 to 0.99999
NPA	220 m -------------	N/A -----------	$1\text{-}1\text{x}10^{-7}$/h	10 s	$1\text{-}1\text{x}10^{-4}$/h to $1\text{-}1\text{x}10^{-8}$/h	0.99 to 0.99999

43 ICAO Annex 10 Vol.1 Table 3.7.2.4-1 Signal-in-space performance requirements
44 Swedish RNP Section 3.2 Aviation requirements
45 US FRP Table 4-2 Aviation performance-based navigation requirements

	556 m	N/A				
APV I	16 m ------------- 40 m	20 m ----------- 50 m	1-2x10^{-7} per approach	10 s	1-8x10^{-6} in any 15 s	0.99 to 0.99999
APV II	16 m ------------- 40 m	8 m ----------- 20 m	1-2x10^{-7} per approach	6 s	1-8x10^{-6} in any 15 s	0.99 to 0.99999
Cat I	16 m ------------- 40 m	6 to 4 m ----------- 15 to 10 m	1-2x10^{-7} per approach	6 s	1-8x10^{-6} in any 15 s	0.99 to 0.99999
Cat II	± 7.5 m	~ 1 m				
Cat III	± 3 m	~ 1 m				

2. Maritime and Inland Waterways Navigation

The global fleet comprises, approximately, 80000 merchant vessels, 2.7 million fishing vessels and 29 million recreational vessels. In inland waterways in Europe, there are more than 13500 vessels offering inland freight transport and about 350 cruise ships[46]. Approximately 90% of world trade is carried by sea. About 400 million passengers transit European ports yearly. The European fishing fleet catches 5 million tonnes of fish every year. There are about 13000 kilometres of inland waterways connecting European regions above CEMT Class IV, which serve to transport more than 145 billion tonne-kilometres of cargo annually (2016)[47]. A large ship costs more than 100 million euro, and the cargo of a very large crude carrier may worth more than 200 million euro. The costs associated to an accident of a crude carrier can be above millions of euro.[48]

Figure 45 shows historical data about international seaborne transport. We see a clear rising trend for tons of cargo loaded, with economic cycles also showing. Global seaborne trade has doubled in the last 18 years.

GNSS-enabled economy in the European maritime sector accounts for 115000 million euro. GNSS indirect impact in the maritime sector ranges between 145 and 354 million euro[49].

Figure 45 – International seaborne trade (Credit: United Nations)

46 Inland Navigation in Europe - Market Observation 2017 publication by the Central Commission for the Navigation of the Rhine

47 Evaluation of RIS Implementation for the period 2006-2011

48 www.gsa.europa.eu, www.ec.europa.eu/eurostat

49 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

Maritime transport takes place in different environments or phases of navigation, including inland waterways, harbour approach and entrance, coastal waters and ocean waters. Ocean navigation occurs when the ship is beyond the continental shelf and more than 50 nautical miles from land. Coastal navigation occurs when the ship is above the continental shelf or within 50 nautical miles from shore. Harbour approach and entrance, and inland waterways, normally takes places in restricted waters, where ships must navigate through well-defined channels.

Maritime navigation requirements depend on the phase of navigation, and are based in those provided by IMO. Table 13 summarises the principal requirements for maritime navigation.

Table 13 – Requirements for maritime navigation[50],[51],[52],[53]

Phase or application	**Accuracy**	**Availability**	**Continuity**	**Time to alert**
Ocean waters	100 m (95%)	99.8%		
Coastal waters	10 m (95%)	99.8%	99.97% in any 15 min	10 s
Harbour approach and entrance	10 m (95%)	99.8%	99.97% in any 15 min	10 s
Inland waterways	2 to 10 m	99.9%		
Lock operation	1 m			
Bridge operation	1 m			
Fishing	10 m			
Hydrography	0.1 to 1 m			
Marine engineering	0.1 to 1 m			
River engineering and construction	0.1 to 5 m	99%		
Surveying	Horizontal: 0.5 to 5 m Vertical: 0.05 m			

[50] IMO resolution A.1046(27)
[51] Swedish RNP Section 3.3 Marine requirements
[52] US FRP
[53] Commission Regulation (EC) No 415/2007

3. Land-based Navigation

As described previously, the aviation and maritime communities are coordinated worldwide, with international organisations defining, among many other things, strict positioning and navigation user requirements. Moreover, those communities have developed and operate ad-hoc navigation infrastructure to fulfil their requirements.

The situation for the land-based community is different. In general, there are no international standards regulating land operations and there is not an ad-hoc navigation infrastructure designed for them (an exception could be the railways sector). Land-based applications exploit the available radio navigation systems to the best possible. As those systems evolve and increase their performance, new applications are possible which take advantage of the higher accuracy in positioning and timing.

3.1 Road Transport

The European road network has an extension of about 2 million kilometres, where almost 300 million vehicles circulate. Considering personal navigation devices, systems installed on vehicles and smartphones, the penetration of GNSS is virtually 100%[54].

GNSS-enabled economy in the road sector accounts for 290000 million euro. GNSS indirect impact in the road sector ranges between 15000 and 16000 million euro[55].

The present accuracies of GNSS are on the order of metres, which allows different applications in the road sector to exploit satellite navigation systems. The most extended application is point-to-point navigation, following turn-by-turn indications given by the navigation device. If vehicles install a return communication link, fleet management operations are also possible, where a control centre knows in real time the location of the fleet. The same principle serves for tracking of dangerous goods. Some European countries have introduced telematics road user charging mechanisms, where vehicle are charged based on their recorded position. This system permits the removal of physical tolls in highways, eliminating also queues and saving time for the final user. Several insurance companies offer to their clients the installation of an on-board tracking system, which records usage time and statistics of vehicles. Clients accepting this service get a discount on their insurance premium, under the idea that they will drive in a safer way. It would also be possible to adapt the insurance costs to the real usage of the vehicle. Drivers and passengers would also benefit from automatic emergency calling. If a vehicle detects it has suffered an accident, it automatically sends an alert to emergency services, providing its exact coordinates. Additional parameters, like, for example, the speed before the accident, would permit a first estimation about the severity of the damage. Finally, advanced GNSS complemented with other technologies, like radar or lidar, would open the possibility of autonomous driving.

54 www.gsa.europa.eu, www.ec.europa.eu/eurostat, www.ec.europa.eu/transport

55 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

As already mentioned, there are not internationally regulated requirements defined for these applications. Instead, the natural evolution of GNSS, with their ever-increasing accuracy, permits the adoption of satellite navigation services for more complex and demanding operations. Table 14 shows the performances needed for a selection of road transport applications.

Table 14 – Requirements for road transport[56,57]

Application	**Accuracy**	**Availability**	**Integrity**	**Time to alert**	**Alert limit**
Navigation and route guidance	1 to 20 m	95%		5 s	2 to 20 m
Automated vehicle monitoring	0.1 to 30 m	95%		5 s to 5 min	0.2 to 30 m
Collision avoidance	10 cm	99.9%		5 s	0.2 m
Emergency response	0.1 to 4 m	99.7%		30 s	0.2 to 4 m
Vehicle tracking	1 to 50 m	95 to 99%		5 s	50 m
Fleet management	20 to 50 m	95%		5 s	50 m
Emergency call	1 to 15 m				
Road assistance	1 to 15 m				
Safety & Liability critical transport	Horizontal: 1 m Vertical: 4 to 6 m		$1\text{-}1\times10^{-9}$/h	6 s	

3.2 Agriculture

There are 11 million farms in Europe, which account for about 40% of the EU's land area. Europe has about 330 million livestock, and produces yearly 43 million tonnes of meat. The agriculture sector employs 22 million regular workers, and exports annually goods for a value of 120000 million euro. Approximately 10% of tractors sold in Europe at present include a GNSS receiver[58].

56 SafeTRIP project
57 US FRP
58 www.ec.europa.eu/agriculture, www.ec.europa.eu/eurostat, www.gsa.europe.eu

GNSS-enabled economy in the agriculture sector accounts for 144000 million euro. GNSS indirect impact in the agriculture sector ranges between 26000 and 35000 million euro[59].

The application of GNSS solutions to agriculture can generate improvements in efficiency, productivity and, at the same time, reduced costs and environmental impact. This results in a more efficient and sustainable agriculture sector, which is under a continuous pressure for growth. Table 15 shows the positioning requirements of several applications. At present, GPS complemented by EGNOS provides horizontal errors in the one to two metre range. This accuracy level covers most of the applications shown on the table.

Table 15 – Requirements for agriculture[60,61]

Application	**Accuracy**	**Availability**	**Time to alert**	**Alert limit**
Harvest mensuration	30 cm	99%	5 s	60 cm
Precision irrigation	15 cm	99%	5 s	25 cm
Field measurement and boundary mapping	2.5 m			
Land parcel identification	2.5 m			
Post-harvest pickup	2.5 m			
Supervised tracking of livestock	2.5 m			
Individual livestock positioning	2 to 5 m			
Virtual fencing	2 to 5 m			
Basic-value crop cultivation	1 m			
Fertilising and reaping	1 m			
High-value crop cultivation	2 cm			
Sowing and transplanting	2 cm			

59 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

60 www.gsa.europa.eu

61 US FRP

3.3 Mapping and Surveying

Mapping and surveying deal with accurately measuring the absolute position of points on the Earth, and its relative position between them, including distance and angles. It deals also with representing this information on a map. The surveying community has some of the most demanding requirements worldwide, up to the millimetre level for applications like seismic monitoring. They use almost exclusively GNSS and its augmentations, including differential GNSS networks either in real time or in post-processing. There are many application areas under this category, like the establishment of geodetic reference networks, natural resource management, cadastral survey, engineering and construction, demographics, geophysics, earthquake and volcanic monitoring, plate tectonics, land movements, etc. Table 16 shows the requirements for some of these applications. GNSS plus EGNOS allows those applications with requirements above the metre level. For applications that need centimetre or even millimetre level accuracy, the use of differential GNSS networks is required.

GNSS-enabled economy in the mapping and surveying sector accounts for 71000 million euro. GNSS indirect impact in the mapping and surveying sector is approximately of 4000 million euro[62].

Table 16 – Requirements for mapping and surveying[63,64]

Application	**Accuracy**	**Availability**	**Continuity**	**Time to alert**	**Alert limit**
Control survey for construction	Centimetre level				
Soil survey	0.05 to 10 m	99%		5s to 5 min	0.09 to 15 m
Surveying for water control	0.05 to 10 m	99%		5s to 5 min	0.09 to 15 m
Surveying for land levelling	15 cm	99%		5 s	25 cm
Earthquake and volcanic monitoring	1 to 10 mm				2 to 20 m
Static survey	Horizontal: 1.5 cm Vertical: 4 cm	99%	$1-1x10^{-4}$/h to $1-1x10^{-8}$/h		
Hydrographic	Horizontal:	99%	$1-8x10^{-6}$/15s		

62 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

63 GSA, GNSS Market Report, version 5 (2017)

64 US FRP

survey	3 m Vertical: 15 cm				
Topographic mapping	1 to 10 mm				
Cadastral survey	1 to 10 cm				
Ground control points	1 m				

3.4 Location-based Services

Miniaturisation and other technological developments have made possible the integration of GNSS receivers in different personal devices, like smartphones, tablets, smart watches, fitness gear, and digital cameras. This has brought an exponential growth of location-based services, where the position of the user is exploited to offer him a broad variety of services. Examples of these applications are personal navigation, geo-advertising, gaming and augmented reality, personal tracking, social interaction, sports monitoring, and emergency calls. The market characterises for being very innovative and dynamic, with new devices and applications appearing continuously. It also presents some specific requirements, like a fast time to first fix and the necessity to operate in difficult environments, including urban canyons and indoors navigation. To overcome these difficulties, it is common that GNSS sensors are integrated with other sources of information, like wireless networks, embedded sensors and inertial navigation systems.

Presently there are about 5000 million devices worldwide with GNSS capacity, with expectation to grow to about 9000 million by 2023[65].

GNSS indirect impact in the location based services sector is approximately of 700 million euro[66].

Most of the applications mentioned above are possible with a location accuracy of a few metres, and are based at present on GPS alone. In the next future, the appearance of new GNSS constellations and the integration with SBAS will reduce further the positioning error, making these applications more reliable and permitting the development of new ones.

3.5 Railways

65 www.gsa.europa.eu
66 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016

The rail sector currently uses GNSS for several non-safety critical applications, like asset management, fleet management and passenger information. Signalling and control, which are safety critical applications, employ expensive ground and on-board equipment, like beacons and balises. In the next future, it is expected the inclusion of GNSS for these safety critical applications. This will open the possibility to rationalise the current infrastructure, reducing costs while keeping or increasing safety. This could be especially important on remote locations, where the ground infrastructure is a limiting factor. The inclusion of GNSS on the signalling and control system will vary for different regions in the world. In the US, GNSS will be the primary means of positioning information for Positive Train Control, PTC. In Europe, investigations are ongoing to include GNSS as a complementing system for safety-relevant operations in the European Railway Traffic Management System, ERTMS[67]. Figure 46 shows the roadmap towards the adoption of GNSS into the ERTMS system. This roadmap is a collaboration between the European Commission, the European GNSS Agency, the European Union Agency for Railways, the European Space Agency, the Shift2Rail Joint Undertaking and industry, and its objective is to have GNSS available for train positioning in 2020.

Table 17 shows the position requirements for different rail transport applications.

Table 17 – Requirements for rail transport[68]

Application	**Accuracy**	**Availability**	**Time to alert**	**Alert limit**
Positive train control	1 m	99.9%	6 s	2 m
Track defect location	30 cm	99.9%	30 s	60 cm
Automated asset mapping	20 cm	99.9%	30 s	40 cm
Surveying	2 cm	99.7%	30 s	4 cm
Bridge and tectonic monitoring for bridge safety	2 mm	99.7%	30 s	4 mm

67 GNSS Market Report, Issue 4, March 2015, GSA

68 US FRP

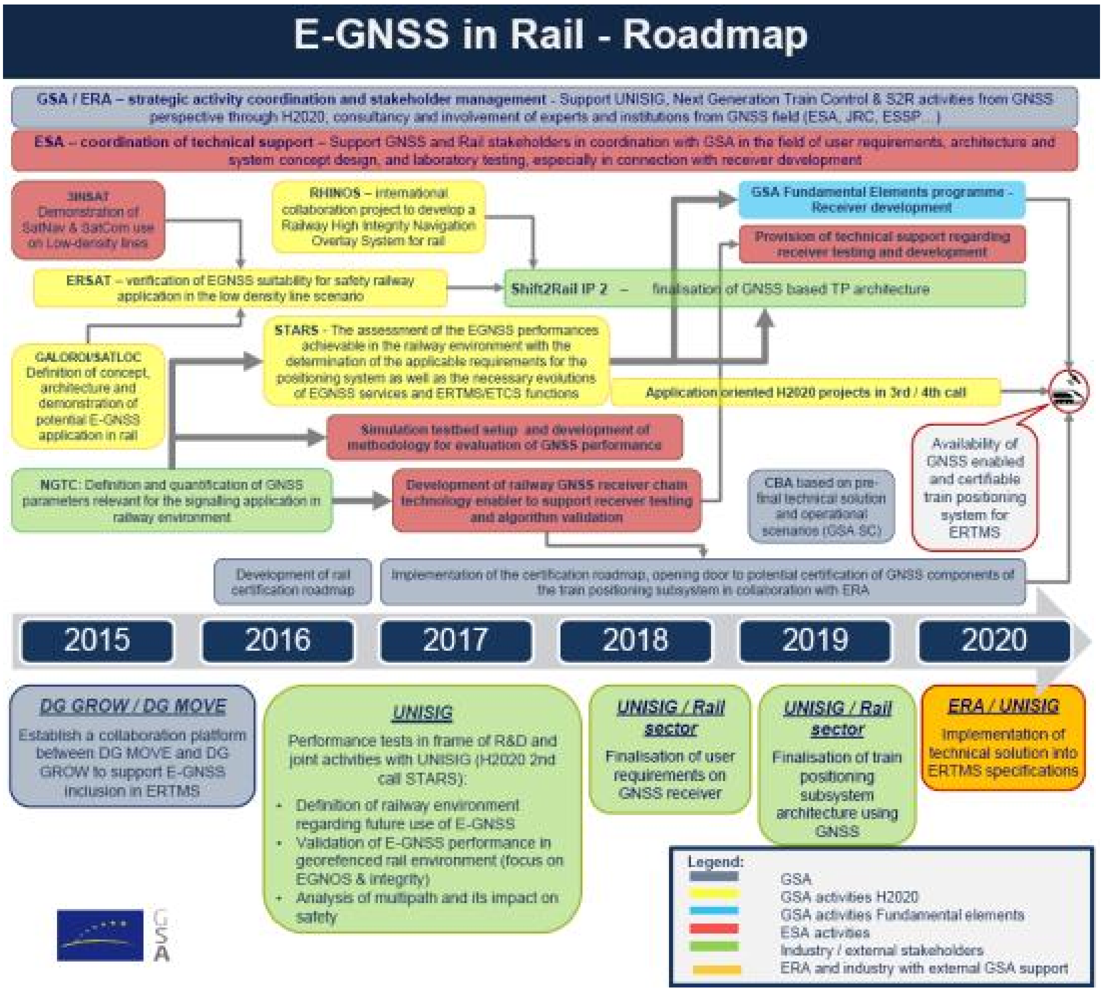

Figure 46 – EGNSS in rail roadmap (Credit: GSA)

4. Space user requirements

GNSS systems are intended to be used on the surface of the Earth. However, navigation signals can also be received at certain altitudes above the surface. The GPS terrestrial service volume covers the Earth to a height of 3000 kilometres above its surface, while the GPS space service volume covers altitudes from 3000 to 36000 kilometres above the surface[69]. Galileo service volume extends up to a height of 30.48 km. above Earth's surface, while the space service volume is under definition[70]. Beside the committed coverages, navigation antenna's side lobes transmit the navigation signals to other areas beyond those.

Satellites increasingly embark GNSS receivers for attitude and orbit control, as well as for timing purposes. The reception of GNSS signals in space depends on the satellite's orbit. At orbits below GNSS constellations, like the one shown in Figure 47, reception is possible from zenith (blue line) and nadir (green line). The reception from zenith is direct from the GNSS satellite, while the reception from nadir may include the transmission of the GNSS signal through Earth's atmosphere. There is also a fraction of the orbit where the Earth blocks signal reception (red line). This situation changes also with the orbital plane. If the orbital plane of the receiving satellite is perpendicular to the orbital plane of the GNSS satellite, reception may be continuous.

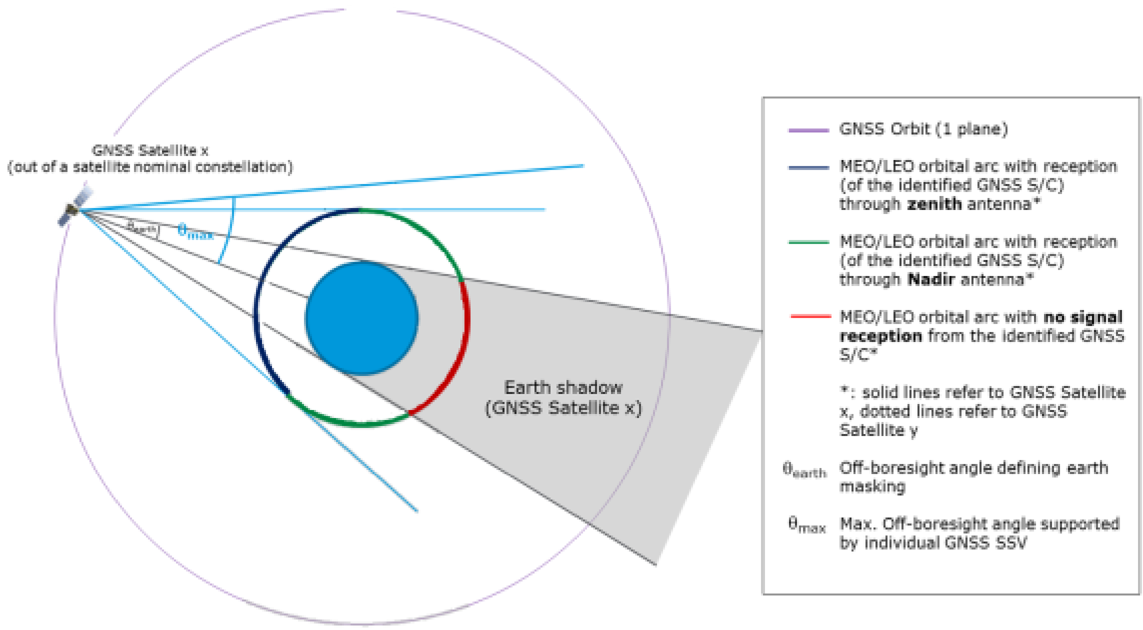

Figure 47 – Reception of GNSS signals at orbit heights lower than nominal GNSS heights (Credit: ESA)

For orbital heights above GNSS constellation, as represented in Figure 48, reception of GNSS signals is only possible in a small portion of the orbit (green line), which depends on the maximum off-boresight angle supported by the GNSS satellite. Besides, GNSS signals may need to travel through Earth's atmosphere to reach the receiver. Again, the situation changes with the orbital plane. In this

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69 GPS Standard Positioning Service Performance Standard. September 2008

70 Galileo Initial Services - Open Service, Service Definition Document. December 2016

case, if the orbital plane of the receiving satellite is perpendicular to the orbital plane of the GNSS satellite, reception may be impossible.

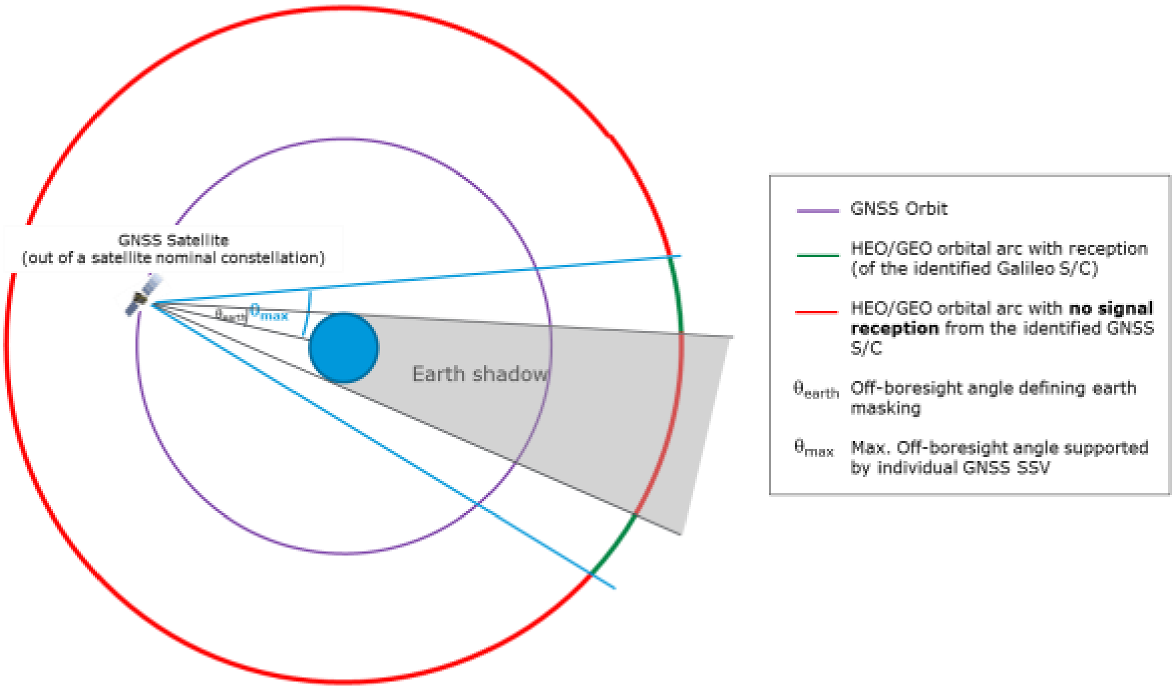

Figure 48 – Reception of GNSS signals at orbit heights higher than nominal GNSS heights (Credit: ESA)

Table 18 shows the positioning and timing requirements for different space user applications.

Table 18 – Requirements for space users[71]

Application	**Accuracy**
On-board autonomous navigation	3D position: 1 metre Timing: 1 microsecond
Earth observation satellites	3D position: 10 cm (real-time) 3D position: 5 cm (post-processed)
Altimetry satellites	Altitude: 3 mm (post-processed)
Occultation measurements	3D position: 10 cm (post-processed)

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5. Precise Timing and Synchronisation

Besides three-dimensional position, GNSS provide a very precise time and frequency reference. The exploitation of this service for timing and synchronisation processes is becoming fundamental for critical infrastructures like the telecommunication networks, the energy distribution networks and the financial markets. These sectors share very stringent requirements in terms of robustness and reliability. GNSS-enabled economy in the telecommunication, utilities and banking sectors accounts for 46000, 11000 and 680000 million euro, respectively. GNSS indirect impact in the utilities sector ranges between 3500 and 4800 million euro[72].

Cellular telecommunication networks use GNSS for synchronisation of timeslots and handover between base stations, operations for which they require an accuracy of microseconds. Satellite communications networks use GNSS for synchronisation of Time Division Multiple Access links. Here, the required accuracy is on the order of nanoseconds. The evolution of telecommunication networks towards higher frequencies and data rates will imply stronger requirements in timing accuracy.

In the electric power grid operation, timing is needed to synchronise the measurements of voltages and currents taken along the network. These measurements are critical for monitoring and control the stability of the electrical grid. The required accuracy is approximately of microseconds.

Financial markets use GNSS for timestamping of operations, where an accuracy of milliseconds is enough. Table 19 summarises the requirements for these timing and synchronisation applications.

Table 19 – Requirements for timing and synchronisation applications[73,74]

Application	**Accuracy**
TDMA for satellite communications	Nanoseconds
Synchronisation of timeslots and handover between base stations in Professional Mobile Radio and Cellular Networks	Microseconds
5G and DVB	~ 10 nsec
Electric network monitoring	Microseconds
Financial transaction timestamp	Milliseconds
Timing for telecommunications in rail applications	340 nanoseconds

6. Emerging applications

72 Analysis of GNSS impact on EU economy, VVA Consulting for the European Commission, 2016
73 GSA – GNSS market report
74 US FRP

The market of autonomous, unmanned and remotely controlled vehicles is experiencing an exponential expansion. This growth reaches all transport sectors and applications, including autonomous cars, robotic tractors, unmanned ships or remotely piloted vehicles, to mention a few examples. This section provides some basic concepts about autonomous navigation, and describes several state-of the-art systems that are under development nowadays.

Unmanned or autonomous vehicles are not new. Armies around the globe have used them in the battlefield for decades, or even more. However, a combination of advances in electronic miniaturisation, computing power, software, communications, sensor fusion and navigation systems has opened their usage to a much broader public. Besides military functions, this type of vehicles have found many applications also in the civil domain like, e.g., autonomous driving, unmanned tractors, parcel delivery, traffic control, or remote sensing. We anticipate that this is just the beginning, with more and new applications appearing continuously.

The expansion of a technology normally comes together with an expansion in the terminology used to refer to it, which, sometimes, is confusing. We present below a short list with the principal terms employed in this emerging sector:

- Unmanned vehicle. A vehicle without persons on-board. It may be autonomous or remotely controlled.
- Unmanned Aerial Vehicle, UAV. An unmanned vehicle that flies. Again, it may be autonomous or remotely controlled.
- Remotely Piloted Aircraft System, RPAS. An unmanned vehicle that flies and it is controlled at a certain distance by a person, normally on ground. Highly advanced military versions, making use of satellite communications, can operate in any part in the world, independently of the location of the controller.
- Autonomous vehicle. A vehicle that operates without human intervention. It may have passengers.
- Drone. Originally, an unmanned aerial vehicle. The term has reached a lot of popularity, and now it is commonly used for every vehicle that is autonomous or remotely controlled.

Autonomous vehicles need to have a precise knowledge of the environment and the surroundings where they are operating. To do so, they exploit a combination of different sensor data: radars, lidars, visible and infrared cameras, ultrasonic sensors, inertial navigation sensors, GNSS… These sensors should be able to provide a full picture of the situation where the vehicle is functioning, including the exact distances and velocities of all the elements in the field, like other cars, pedestrians, cyclists, tress, or buildings. Traffic lights and circulation signals, for example, speed limits or priorities, are also fundamental. Finally, autonomous systems need to process all this information in real time to take the appropriate decisions to reach their destiny. There might be a lot of challenging situations, like anticipating if a cyclist is going to change lane, a non-functioning traffic light, a pedestrian crossing through a not allowed spot, or a police officer giving instructions in a city. Additionally, the on-board sensors should provide this information irrespective of weather and visibility conditions, and during the night.

As we see, the need for information in autonomous systems goes beyond knowing their exact position. They also need to know the position and status of surrounding elements. However, GNSS systems have an important role for autonomous vehicles. All the sensors described before play a tactical role, providing information needed for short-term decisions, like changing lane or decelerating to avoid a collision. On the other hand, GNSS plays a strategical role, providing information needed for long-term decisions like which is the best route to follow.

Nowadays, cars include many automatic functions to help drivers in their task. Cruise control keeps the speed of the vehicle at the level specified by the driver. Radars and proximity sensors allow keeping a constant distance with the vehicle preceding us. Automatic braking systems reduce the velocity of a car if they detect the risk of a collision. Lane control systems control the steering functions, to maintain the car inside its lane lines. However, autonomous driving is still much more difficult than this, since it needs to cope with every situation under any combination of traffic, environment, weather and visibility conditions. Figure 49 depicts the different phases towards the development of autonomous driving. As long as new automatic features are included, the driver tasks of control and monitoring are reduced. The goal of this process is to reach a situation of full automation, where drivers will not be needed any more.

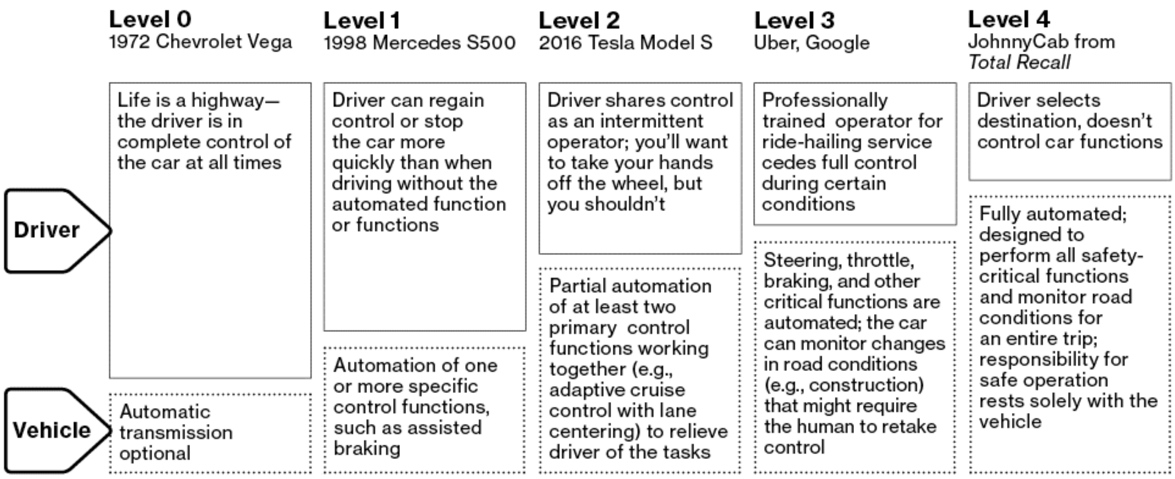

Figure 49 – Steps towards autonomous driving (Credit: Bloomberg Business Week)

The principal car manufacturers have plans to develop autonomous cars. Other technological companies are doing the same. For example, Google and Uber have two of the most advanced self-driving systems of the moment. These systems have done millions of kilometres of tests in real driving conditions. However, for regulatory reasons, and for prudent practice as this new technology is starting, up to now the self-driving cars have always a driver that can take full control of the system if needed. As we see in Figure 49, these vehicles are just one-step below reaching the full automation level. Goggle plans to have a complete autonomous car by 2020.

Figure 50 – Google self-driving car (Credit: Google)

In October 2016, Tesla announced that all their car models will include the hardware and software needed for a total autonomous navigation. Figure 51 shows the different cameras and sensors that Tesla's cars will have on-board. Thanks to this equipment, the car will have a vision up to 250 metres around, in all weather conditions. Tesla plans to make a demonstration trip between Los Angeles and New York by the end of 2017. It is very interesting to note that Tesla is developing a product even knowing that present regulations do not allow it. Their hope is that laws will change to adapt to the new scenarios that modern technology makes possible.

Figure 51 – Cameras and sensors in Tesla's self-driving car (Credit: Tesla)

Passenger transport is also progressing towards autonomous driving. Mercedes-Benz has developed a semi-autonomous bus, shown in Figure 52, and has tested it in a bus rapid transit route between

Amsterdam's Schiphol airport and the town of Haarlem. The bus speed is limited to 70 km/h, and, as before, has a driver to take control of it if needed.

Figure 52 – Mercedes-Benz semi-autonomous bus (Credit: Mercedes-Benz)

Driving autonomously in roads and cities is a very complex task due to the enormous variability of scenarios that are possible: heavy traffic, cyclists, pedestrians, traffic lights, road works … On the other hand, agriculture fields present a much simpler situation, and it is an ideal environment to test the technologies involved in automatic driving. CNH Industrial has recently presented an autonomous tractor, shown in Figure 53 that can perform the tasks of planting, spraying or harvesting. Interestingly, this tractor, as we see in Figure 53, does not have a cabin for a driver. The farmer can, however, monitor and control the tractor in real time from a remote location, using a laptop or a cellular phone.

Figure 53 – Autonomous tractor (Credit: CNH Industrial)

The development of autonomous vehicles is not limited to terrestrial applications. Autonomous or remote controlled ships may become a reality in a not too distant future. The FP7 project MUNIN, Maritime Unmanned Navigation through Intelligence in Networks, aimed to develop and verify a concept for an autonomous ship. Figure 54 presents MUNIN's vision towards the development of autonomous navigation. In a near-term future, personnel on an onshore control centre could replace the ship's crew. These personnel, using satellite communication links, would receive data from the ship's sensors and would control it remotely. MUNIN also considers that it would be possible for and on-board computer system to control automatically the ship. Their concept of autonomous ship combines both solutions. An on-board control and navigation system would govern the behaviour of the vessel. Additionally, personnel at an onshore control centre would be monitoring the process. If a situation required it, these personnel would be ready to take control of the ship at any time.

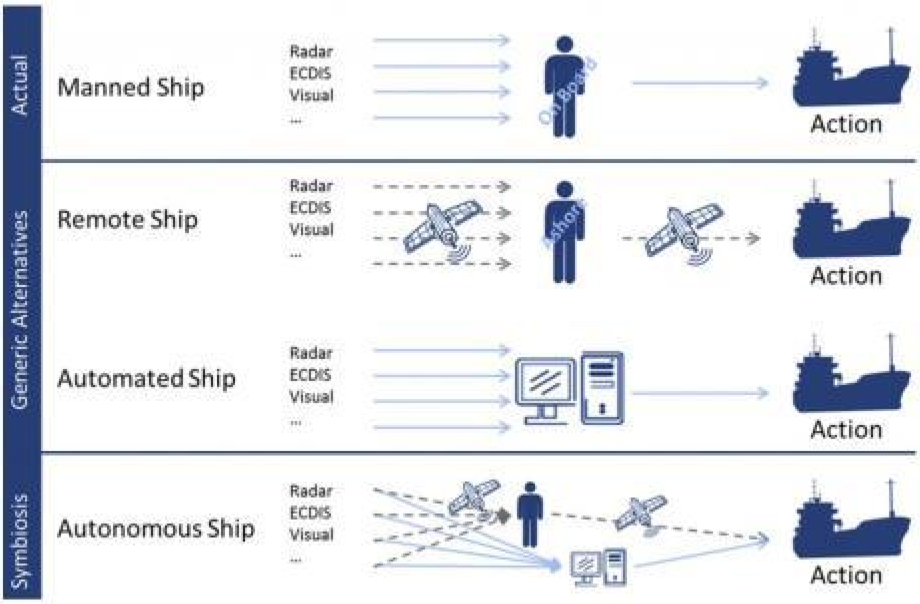

Figure 54 – Steps towards an autonomous ship (Credit: MUNIN project)

Rolls-Royce is very active in the research and development of autonomous ships. They have presented a roadmap towards the development of autonomous navigation, which we reproduce in Figure 55. The evolution is gradual, beginning with the inclusion of remote operations for certain functions, which will allow reducing on-board crew. By 2020, they expect the first remote controlled vessels operating locally. The process will continue with the introduction of remote controlled coastal vessels, by 2025, and remote controlled ocean vessels, by 2030. Finally, by around 2035, they expect the first autonomous ships to be operating on a global scale.

Figure 55 – Rolls-Royce roadmap towards autonomous navigation (Credit: Rolls-Royce)

Some countries are leading the initiative of maritime autonomous navigation. Norway, for example, has stablished the first test zone in the world for unmanned ships. The test field is located in the area of the Trondheim fjord.

Finally, unmanned air vehicles are also finding new applications every day. Originally, UAVs were developed by military forces worldwide. Indeed, the most advanced UAVs are still those developed by the military. Some of them, remotely piloted using high-speed satellite communication links, can operate in any place in the world.

In the civil domain, it is very well known the initiative by Amazon of parcel delivery using drones. The service is called Amazon Prime Air, and intends to use drones of up to 25 kilograms flying below 120 metres altitude. The objective is to deliver autonomously parcels of a maximum of 5 kilograms at distances of less than 16 kilometres in less than half an hour. Again, the company started research on this service before regulations allow it.

Figure 56 – Amazon Prime Air delivery service (Credit: Amazon)

The market of UAVs is probably, among autonomous vehicles, the one that is developing faster. The list of applications grows every day, and only imagination limits it. Livestock control, crop monitoring, construction, emergency management, property surveillance, infrastructure management, advertising or even drone races are just a few of the fields where drones operate today or will do it in the near future. As it happens with other types of autonomous vehicles, regulations regarding the usage of UAVs will need to be reviewed, to take advantage of the benefits they might bring but without limiting safety, security and privacy aspects.

Table 20 shows the requirements for autonomous vehicles. In general, for the same application, autonomous vehicle requirements are more stringent than manned vehicle ones. There is a lot of ongoing research into this area. Thus, we can expect that the requirements list will be refined during the following years for more and different applications.

Table 20 – Requirements for autonomous vehicles[75]

Application	**Accuracy**	**Availability**	**Alert limit**	**Time to alert**
Road collision avoidance	10 cm	99.9%	20 cm	5 s
Automated vehicle monitoring	Up to 10 cm	>95%		5 s

ANNEX 3. Actors, Roles and Responsibilities

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Annex 3 provides a description of the key stakeholders involved in the management, development, operation and regulation of radio navigation systems, namely:

- European Commission.
- European GNSS Agency.
- European Space Agency.
- European Defence Agency.
- Galileo service operator, Spaceopal.
- EGNOS service operator, European Satellite Services Provider.
- Eurocontrol.
- SESAR Joint Undertaking.
- European Aviation Safety Agency.
- European Maritime Safety Agency.
- European Fisheries Control Agency.
- European Union Agency for Railways.
- Shift2Rail Joint Undertaking.
- European Maritime Radionavigation Forum.
- International Maritime Organisation.
- International Association of Marine Aids to Navigation and Lighthouse Authorities.
- International Civil Aviation Organisation.

To know more about the different organisations, please visit the following websites:

- https://europa.eu/european-union/index_en
- http://ec.europa.eu/growth/index_en
- www.gsa.europa.eu
- www.gsc-europa.eu
- www.esa.int
- www.eda.europa.eu
- www.spaceopal.com
- www.essp-sas.eu
- www.eurocontrol.int
- www.sesarju.eu
- www.easa.europa.eu
- www.emsa.europa.eu
- www.efca.europa.eu
- www.era.europa.eu
- www.shift2rail.org

- www.emrf.eu
- www.imo.org
- www.iala-asim.org
- www.icao.int

1. European Commission

The European Commission represents the general interest of the European Union, and is the driving force in proposing legislation to European Parliament and Council, administering and implementing

EU policies, enforcing EU law jointly with the Court of Justice, and negotiating in the international arena.

Within the European GNSS programs, the European Commission is responsible for the political dimension and the high-level mission requirements. Its role is the management of the GNSS programmes and the funding: ensure coordination among stakeholders, establish delegation agreements, monitor risks and define the key decision stages for the implementation of the programmes. The European Commission initiated, in particular, studies on the overall architecture, the economic benefits and the user needs for Galileo. These include the GALILEI studies that addressed the local architectures, interoperability, signals and frequencies. Moreover, they provided a market observatory and catered for investigations into legal, institutional, standardisation, certification and regulatory issues.

The Directorate General for Internal Market, Industry, Entrepreneurship and SMEs, DG GROW, oversees the European Commission's activities in the field of satellite navigation. DG GROW is responsible for delivering the EU's space policy via the two large-scale programmes, Copernicus and Galileo, as well research actions to spur technological innovation and economic growth. Following the entry in force of Regulation (EU) 1285/2013, the European Commission is empowered as the Programme Manager of Galileo and EGNOS. The Satellite Navigation Programme Directorate in DG GROW is the main responsible of the implementation of the EU GNSS Programmes.

In addition to the Programme management tasks, DG GROW also analyses the impact that satellite navigation has on competitiveness in four main segments of the EU economy:

- Upstream. The contribution of the European space industry to the building of global satellite navigation systems.
- Service provision. European businesses supplying commercial or public positioning, navigation, or timing services.
- Downstream. The European applications industry, which depends on service provision to supply the hardware and software needed to exploit satellite signals.
- End users. Businesses using services and applications provided by satellite signals.

The Full Operational Capability phase of the Galileo programme is fully funded by the European Union and managed by the European Commission. The European Commission and ESA have signed a delegation agreement by which ESA acts as design and procurement agent on behalf of the European Commission.

The European Commission is the EGNOS Programme Manager. The operations of EGNOS have been delegated the European Satellite Services Provider, ESSP, under a contract with the European Commission.

2. European GNSS Agency

The European GNSS Supervisory Authority was initially established as a Community Agency on 12 July 2004. On 9 November 2010, it was restructured into an agency of the European Union called the

European GNSS Agency, GSA, ensuring the continuity of its activities. The headquarters of the GSA are located in Prague. The GSA's mission is to support European Union objectives and achieve the highest return on European GNSS investment, in terms of benefits to users and economic growth and competitiveness, by:

- Designing and enabling services that fully respond to user needs, while continuously improving the European GNSS services and Infrastructure.
- Managing the provision of quality services that ensure user satisfaction in the most cost-efficient manner.
- Engaging market stakeholders to develop innovative and effective applications, value-added services and user technology that promote the achievement of full European GNSS adoption.
- Ensuring that European GNSS services and operations are thoroughly secure, safe and accessible.

The GSA serves as the essential link between space technology and user needs, translating Galileo and EGNOS signals into valuable, reliable services for European citizens.

One of the main task of the GSA is in the Market Development domain. In line with the mission, the GSA works to foster the adoption of EGNOS and Galileo, interacting constantly with the different Users Communities and implementing adoption roadmaps to remove the barriers and to develop the related value chain and the market. The GSA is for example working with receiver and chipset manufacturers for the inclusion of Galileo and its activation in main mass market, automotive and professional receivers. This has allowed having the most of chipset brands adopting Galileo before the launch of Galileo Initial Services. In the same way, the GSA is working with major carmakers and their suppliers to foster innovation in the use of EGNSS innovative features for all the emerging applications such as autonomous driving and mobility as a service application. The use of EGNOS in aviation has been one of the main target of GSA, who supported the procedures that enables the European airports to use the system and the airlines to retrofit and certify the aircraft. This is completed by target actions in other transport segments and in the professional domain.

In addition, under delegation of the Commission, the GSA is developing innovative EGNSS applications and receivers, especially promoting the competitiveness of the downstream European industry and SMEs.

To ensure that EGNSS services fully correspond to user needs, the GSA has developed of number of tools and processes allowing a constantly updated knowledge of the GNSS market characteristics, the available GNSS user technologies, and of the users' requirements. The GSA publishes its "GNSS Market Report" and "User Technology Report" on a bi-yearly basis, and periodically organises a "User Consultation Platform" to validate its user requirements documents.

The GSA has been responsible for EGNOS service provision for the past years. During this time, the GSA has supported the uptake of EGNOS to benefit a wide range of users. For example, today, over 200 airports have EGNOS-based approaches, EGNOS-based precision farming benefits over two-thirds of European tractors, and EGNOS is the standard for mapping and surveying in Europe.

The European GNSS Service Centre, GSC, provides the single interface between the Galileo system and the users of the Galileo Open Service and the Galileo High Accuracy Service. The GSA is responsible for the GSC and is supported by Spain, which provides the Galileo Programme the necessary hosting GSC infrastructure and facilities. The GSC is located in a fully secured environment in Madrid, Spain, within the National Institute of Aerospace Technologies (INTA) facilities at Torrejón de Ardoz, overseen by the Spanish Ministry of Defence. When fully developed, the GSC will operate on a 24/7 basis, and offer a range of services, such as:

- Providing the interfaces between the Galileo System and the Open Service users.
- Providing the interfaces between the Galileo System and the High Accuracy Service providers and/or users.
- Hosting the Galileo User Helpdesk.
- Providing a dissemination platform for Galileo-related products.
- Hosting an electronic library with Galileo and GNSS reference documentation.
- Offering on demand retrieval and delivery of data archived in the Galileo Control Centre.
- Supporting the management of the High Accuracy Service.
- Hosting a centre of expertise for OS and CS and SoL service aspects.
- Providing SoL and CS user’s service performance assessment forecasts and notice to users.

In addition to its service provision, the GSA is also responsible for ensuring that Europe’s GNSS signals are secure. Within this function, the GSA is undertaking security accreditation of the complete Galileo system, its operations and services – including the Galileo Open Service, High Accuracy Service and Public Regulated Service. The independent Security Accreditation Board, SAB, oversees all security-related work. The GSA hosts the SAB, and assesses the robustness and resilience of both Galileo and EGNOS and all the services they offer. It is comprised of security experts from each EU Member State. As a result of this focus on security, the GSA is increasing end-user confidence that European GNSS services are available in a secure, resilient and reliable manner.

The Galileo Security Monitoring Centre, GSMC, undertakes the following missions:

- Galileo Security Monitoring. The GSMC monitors and takes action regarding security threats, security alerts and the operational status of systems components.
- Management of PRS access on system level. The GSMC ensures that sensitive information relating to the use of the PRS is suitably managed and protected, and not exposed to the Galileo Operating Centre. The GSMC serves as the interface with governmental entities (through computerised Point of Contract Platforms or POCPs) for requests of cryptographic keys, and with the Galileo core components for managing satellite-related signal messages.
- Implementation of ‘joint action’ instructions. In the event of a security threat to the European Union or to a Member State arising from the operation or use of the system, or in the event of a threat to the operation of the system itself, in particular as a result of an international crisis, the Council, acting unanimously, shall decide on the necessary instructions to the GSA and the concession holder of the system.
- Provide PRS and Galileo security expertise and analysis.

The GSMC is based in Saint Germain en Laye, France, and Madrid, Spain.

3. European Space Agency

The European Space Agency is an international organisation with 22 Member States: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Canada, Bulgaria, Cyprus, Malta, Latvia, Lithuania, Slovakia and Slovenia have cooperation agreements with ESA. ESA's purpose shall be to provide for, and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems

The European Space Agency has a prominent technical role in the design and development of the European navigation programmes. We summarise below ESA's involvement in EGNOS, Galileo, the European GNSS Evolution Programme, EGEP, and the Navigation Innovation and Support Programme, NAVISP.

EGNOS is a project that was initiated by the Tripartite Group whose members were ESA, the European Commission and Eurocontrol. ESA had overall responsibility for the design and development of the EGNOS system. EGNOS was declared operational for non-safety-critical uses in 2009 and for safety-critical aircraft landing approach uses in 2011. After the successful completion of its development, ownership and EGNOS Programme Management was transferred to the European Commission on 1 April 2009.

Under Delegation Agreement from the European Commission, ESA continued its work as System and Procurement responsible for all major evolutions of the EGNOS System under exploitation. In 2015, ESA signed a working arrangement with the GSA confirming the role of ESA as System and Procurement entity for further major evolution of the EGNOS system under exploitation as well as for the design development and qualification of the second generation of EGNOS, named EGNOS V3. EGNOS V3 will provide enhanced services, in particular to civil aviation users, by providing double frequency and multi-constellation augmentation services to user communities. With this new generation, Safety of Life services will be provided based also on Galileo Services, augmented by EGNOS V3 signals. The GSA now manages EGNOS operations through a contract with the European Satellite Services Provider, ESSP.

ESA led the definition, development and In-Orbit Validation phases of the Galileo programme, co-funded with the European Commission. ESA has overseen the design and deployment of the Full Operational Capability Galileo on behalf of the Commission, with system operations and service provision due to be entrusted to the GSA in 2017.

In parallel to the work of ESA on EGNOS and Galileo, ESA is running a number of R&D programmes aimed to prepare the technology of the main systems and its applications. The main two programmes of ESA on this area are EGEP and NAVISP.

The objectives of EGEP, initiated in 2007, were defined with a view to expanding GNSS-related scientific, technical and industrial expertise in Europe, bringing it on a par with international levels. Through forward-looking activities, the programme ensured that European industry has timely availability of competitive and innovative capabilities required for the evolution of EGNOS and Galileo. This applied to future requirements in the short, medium and long term. The objectives of EGEP were the following:

- Define future system architectures for EGNOS and Galileo and prepare the technology for future versions of these systems.
- Support the definition of how to implement the next version of EGNOS, and prepare the technology for it.

- Provide testbeds and system tools.
- Improve ESA's knowledge of GNSS performance monitoring and the principal environmental factors influencing performance.
- Promote and support scientific exploitation of EGNOS and Galileo.

EGEP also provided a framework for scientific research enabled by GNSS, which spans a wide range of disciplines, from atmosphere and climate modelling through time and space references to fundamental physics. These aspects of the programme include initiatives to foster scientific utilisation of EGNOS and Galileo and to support education activities in the field of GNSS.

The objective of NAVISP is to boost Member State industrial competitiveness and innovation priorities in the upstream and downstream navigation sector and to investigate the integration of satellite navigation with non-space technologies and complementary positioning and communication techniques. NAVISP is structured into three elements, with the first developing new space based PNT technologies and concepts, the second focused on industrial competitiveness and the third offering support to Member State national programmes and activities. In a world where satellite-based positioning, navigation and timing services are key enablers – underpinning everything from automated drones to precision farming to electricity grids and financial networks – NAVISP aims to support novel ways of making these services more robust and reliable, and to facilitate the emergence of competitive European actors.

ESA has established a GNSS Scientific Advisory Committee, GSAC, with leading scientists in the field to foster interaction with the scientific community and to support the Agency in setting priorities and selecting proposals for the scientific exploitation of Galileo and EGNOS. The committee also recommends improvements to Galileo and EGNOS for scientific applications and advises on potential secondary payloads for Galileo satellites.

4. European Defence Agency

The European Defence Agency, EDA, was set up in 2004 as an agency of the Council of the European Union. EDA supports its 27 Member States (all EU countries except Denmark) in improving their defence capabilities through European cooperation. Acting as an enabler and facilitator for Ministries of Defence willing to engage in collaborative capability projects, EDA has become the hub for European defence cooperation. Its expertise and networks allow it to cover the whole spectrum: from harmonizing requirements to delivering operational capabilities; from research and innovation to developing technology demonstrators; from training and exercises to maintenance and support to

CSDP operations. EDA also works towards strengthening the European defence industry and acts as a facilitator and interface between Member States' military stakeholders and wider EU policies with an impact on defence. In May 2017, EDA's Member States agreed to reinforce EDA's mission, including by making it the central operator for EU funded defence related activities.

EDA's aim is to foster defence cooperation among its Member States. It is at the service of its members and supports them in commonly agreed priority areas through dedicated cooperative projects. EDA has close links to its national expert counterparts as well as with a number of EU institutions, international organisations and third States. Several Administrative Arrangements with international organisations and Third States (Norway, Serbia, Switzerland and the Ukraine) have been concluded.

In November 2015, EDA's Steering Board tasked the EDA to establish a process for developing a European Military Radio Navigation Policy (since renamed Military Satellite Navigation Policy) to define how the military and defence sectors could benefit from EU satellite navigation programmes. In March 2016, the Steering Board approved that the two-fold objective of this policy should be to scope the potential European secure use of PNT information, including Galileo services, and to define in which situations the Galileo PRS may be used in coordination with other GNSS systems. The Steering Board also encouraged Member States to nominate national experts to work on the preparation of the European Military Satellite Navigation Policy document. In March 2017, the Steering Board decided to approve the European Military Satellite Navigation policy and tasked EDA to establish an Ad Hoc Working Group to produce a Common Staff Target document, based on the policy, without prejudice to the current governance frameworks and national policies, to be presented for approval by early 2018.

Additionally, EDA's Capability Technology, CapTech, group Guidance, Navigation and Control, GNC, is dealing with PNT related technologies. The core mission of a CapTech is to gather advice from the Member States' experts to support and foster R&T and innovations for defence systems. This CapTech covers critical GNC technologies for improved autonomy and automation, increased performance and dependability in support to future defence capability needs. R&T activities within the CapTech aim to contribute to improved operational effectiveness, enhanced situational awareness, safety and security, and to support future PNT superiority needs.

Based in Brussels, EDA is headed by the High Representative of the Union for Foreign Affairs and Security Policy.

5. Galileo service operator, Spaceopal

Spaceopal GmbH is a joint venture founded in 2009 by the partners DLR GfR mbH and Telespazio S.p.A. From November 2010 until June 2017, Spaceopal was the Prime Contractor responsible for Galileo operations under the Galileo Full Operational Capability Operations Framework contract, regulated by two control centres through a worldwide network of ground stations. Since July 2017, following a competitive tender ran by the European GNSS Agency, Spaceopal GmbH continues to operate the Galileo satellite fleet under the Galileo Service Operator contract, ensuring the provision of the Galileo services to the worldwide community.

Since the end of 2016, Galileo Initial Service is available and Spaceopal is actively supporting the completion of the system to expand the services up to full operational capability by 2020.

The fully established constellation and infrastructure of Galileo consists of 30 satellites distributed over three orbits, approximately 20 sensor stations for monitoring the navigation signals, two satellite control centres, one in Oberpfaffenhofen (Bavaria, Germany) and one in Fucino (Abruzzo, Italy), the GNSS Service Centre in Torrejón de Ardoz (Madrid, Spain), several mission-uplink stations and satellite control transmitting stations. As Service Operator of the Galileo system, Spaceopal GmbH provides high-quality navigation and timing for users worldwide.

The core business activities of Spaceopal GmbH, which assure Galileo operation, include:

- Operations management.
- Operations engineering and preparation.
- Maintenance and operations.
- Galileo service provision.
- Launch and early operation phase.
- Galileo data dissemination network.
- Time service provision.
- Geodetic reference service provision.
- In-orbit test services.
- Integrated logistics services.
- Security operations.

Spaceopal GmbH has headquarters in Munich, Germany.

6. EGNOS service operator, European Satellite Services Provider

European Satellite Services Provider, ESSP, was founded in 2001. Since its foundation, ESSP participated in the EGNOS program. ESSP shareholders are seven European Air Navigation Service Providers:

- Skyguide, Switzerland.

- DFS IBS, Germany.
- DSNA, France.
- ENAIRE, Spain.
- NATS, United Kingdom.
- ENAV, Italy.
- NAV, Portugal.

ESSP owns an ANSP certificate and it is under continuous oversight by the European Aviation Safety Agency, EASA.

ESSP's core activity is the operations and service provision of EGNOS. In 2013, the GSA awarded a contract to ESSP to act as the single EGNOS Service Provider for the period 2014 to 2021. During that period, ESSP is in charge of the operations of the ground and space segments, of the overall maintenance of the infrastructure and the compliance with safety standards. ESSP also takes care of the EGNOS users through three dedicated services:

- The Open Service, for applications where human life is not at stake, such as personal navigation, goods tracking and precision farming (available since October 2009).
- The Safety-of-Life Service, where human lives depend on the accuracy and integrity of the signals, became available for its primary purpose of aircraft navigation (beginning with vertical guidance for landing approaches) in March 2011. The LPV-200 service is operational since September 2015.
- The EGNOS Data Access Service, EDAS, which offers internet access to EGNOS data. EDAS is the single point of access for the data collected and generated by the EGNOS infrastructure.

ESSP operates the GNSS Service Centre.

ESSP has offices in Toulouse and Madrid. Toulouse hosts the Headquarters and the System Operations and Compliance Management Units. Madrid hosts the Service Provision Unit.

7. Eurocontrol

Eurocontrol is an intergovernmental organisation with 41 Member States, committed to building, together with its partners, a Single European Sky that will deliver the air traffic management performance required for the twenty-first century and beyond. Eurocontrol has signed Comprehensive Agreements with the Kingdom of Morocco and the State of Israel.

The activities of Eurocontrol include:

- Manage the entire ATM Network (with nearly ten million flights every year) in close liaison with the ANSPs, airspace users, the military and airports.
- Provides an air traffic control service for the Netherlands, Belgium, Luxembourg and northern Germany.
- Handle the billing, collection and redistribution of aviation charges.
- Develop the Centralised Services initiative, which will open up some services to market competition on a pan-European level, generating significant savings and making for greater operational efficiency.
- Support the European Commission, EASA and National Supervisory Authorities in their regulatory activities.
- Perform research, development and validation and make a substantial contribution to the SESAR Joint Undertaking.
- Coordinate civil-military aviation in Europe.

The Eurocontrol navigation team consists of experts in the different fields of navigation infrastructure (including both conventional navigation aids and GNSS) and navigation applications. The navigation team:

- Contributes to navigation-related SESAR projects.
- Supports navigation-related activities of the Eurocontrol Single Sky Directorate.
- Leads stakeholder groups looking at the current status of navigation and its future, in support of the Network.
- Supports the Network Management functions as described in the Network Management Service Catalogue.

The Eurocontrol work on navigation infrastructure supports the deployment of GNSS while ensuring that conventional navigation aids evolve from a primary role to provide redundant services to GNSS. Eurocontrol plays a central role in the introduction of GNSS in the European aviation based on partnership with aviation stakeholders, other European institutions dealing with GNSS (EC, ESA and GSA) and international partners like the FAA. The following key principles apply to the work on GNSS:

- Eurocontrol should ensure the protection of the interests of all aviation users working in consultation with aviation stakeholders, notably airspace users.
- Eurocontrol's approach and involvement on different GNSS systems should be based on its ability to provide benefits to ATM Network performance in terms of capacity, cost efficiency, safety, environment and/or interoperability, with respect to other solutions.
- Eurocontrol can provide valuable, independent and impartial support to the EU in finding how best EGNOS and Galileo can be integrated into the aviation strategy to enhance ATM performance of the SES.

Conventional navigation aids are the ground-based part of the navigation infrastructure. It refers to the navigation aids such as NDBs, VORs, DMEs, as well as ILS and MLS. Eurocontrol is involved in a variety of projects to optimise conventional infrastructure. In particular, the deployment of new facilities to support PBN needs to be considered judiciously, partly owing to cost but more importantly because of spectrum issues. The L-band from 960 to 1215 MHz contains established navigation and surveillance systems (DME, SSR) while a variety of new CNS services (GNSS, ADS-B and others) are also trying to find a home. Infrastructure activities contribute cross-discipline expertise to ensure that new services can be implemented safely. Especially the planning of DME evolution will require a new level of cross-border cooperation in the coming years, because DME/DME positioning is an established GNSS back up while new CNS services are needed just as much for SESAR's trajectory-based operations.

Eurocontrol continues to support ANSPs and airspace users in ensuring that thanks to an interoperable and continual service, navigation systems remain an invisible success story.

The costs of ATM services in Europe (infrastructure, staff and other operational costs) are funded through air navigation charges. ATM services are funded through the “user pays principle”. There are different sorts of air navigation charges: route charges, terminal navigation charges, and communication charges. Eurocontrol bills and collects route charges on behalf of all its Member States.

8. SESAR Joint Undertaking

The SESAR Joint Undertaking, SJU, was established as a public-private partnership under Council Regulation (EC) 219/2007 of 27 February 2007 (as modified by Council Regulation (EC) 1361 / 2008 (SJU Regulation) and last amended by the Council Regulation (EU) 721/2014).

The SJU is responsible for the modernisation of the European ATM system by coordinating and concentrating all ATM relevant research and innovation efforts in the EU. As the technological pillar of Europe's ambitious Single European Sky initiative, SESAR is the mechanism which coordinates and concentrates all EU research and development activities in ATM, pooling together a wealth experts to develop the new generation of ATM.

Founded by the European Union and Eurocontrol, today SESAR unites the whole aviation community through its members. Several members consist of consortia and, together with their affiliates and sub-contractors, represent approximately 100 organisations actively participating in and demonstrating the impact of the SESAR programme on ATM R&D activities in Europe. Additionally, several stakeholders from all sectors or civil and military aviation, ANSPs, airports, equipment manufacturers, staff and the scientific community participate in the Administrative Board of the SJU. In total, SESAR unites around 3000 experts in Europe and beyond.

The members of the SJU are:

- European Commission. Founding member.
- Eurocontrol. Founding member.
- Airbus. Member.
- DFS. Member.
- DSNA. Member.
- Enaire. Member.
- ENAV. Member.
- Finmeccanica. Member.
- Frequentis. Member.
- Honeywell. Member.
- Indra. Member.
- Natmig. Member.
- Nats. Member.
- Noracon. Member.
- Seac. Member.
- Thales Group. Member.

The SJU Administrative Board contains also representation form different stakeholder communities, including:

- Military.
- Civil users of airspace.
- Air Navigation Service Providers, ANSPs.
- Equipment manufacturers.

- Airports.
- Staff in the ATM sector.
- Scientific community.

The mission of the SJU is to develop a modernised ATM system for Europe, which will prevent crippling congestion of the European sky and reduce the environmental impact of air transport. The SJU will therefore coordinate and concentrate all relevant research and development efforts undertaken by its members. The SJU is responsible for the implementation of the European ATM Master Plan and for carrying out specific activities aiming at developing the new generation ATM system capable of ensuring the safety and fluidity of air transport worldwide over the next thirty years.

SESAR's vision builds on the notion of trajectory-based operations and relies on the provision of air navigation services in support of the execution of the business or mission trajectory, meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations. This vision is enabled by a progressive increase of the level of automation support, the implementation of virtualisation technologies as well as the use of standardised and interoperable systems. The system infrastructure will gradually evolve with digitalisation technology, allowing ANSPs, irrespective of national borders, to plug in their operations where needed, supported by a range of information services. Airports will be fully integrated into the ATM network level, which will facilitate and optimise airspace user operations.

Going beyond 2035 towards 2050, performance-based operations will be implemented across Europe, with multiple options envisaged, such as seamless coordination between ANSPs or full end-to-end ANS provided at network level. Furthermore, it is widely recognised that to increase performance, ATM modernisation should look at the flight as a whole, within a flow and network context, rather than segmented portions of its trajectory, as is the case today. With this in mind, the vision will be realised across the entire ATM system, offering improvements at every stage of the flight.

9. European Aviation Safety Agency

The European Aviation Safety Agency, EASA, is an agency of the European Union which has been given specific regulatory and executive tasks in the field of aviation safety. EASA was established by Council Regulation (EC) No 1592/2002 of the European Parliament and of the Council of 15 July 2002 (OJ L 240, 7.9.2002 repealed by Regulation (EC) No 216/2008).

32 Member States form EASA, the 28 Member States of the European Union plus Switzerland, Norway, Iceland, Liechtenstein.

EASA is the centrepiece of the European Union's strategy for aviation safety. Its mission is to promote the highest common standards of safety and environmental protection in civil aviation. The Agency develops common safety and environmental rules at the European level. It monitors the implementation of standards through inspections in the Member States and provides the necessary technical expertise, training and research. The Agency works hand in hand with the national authorities, which continue to carry out many operational tasks, such as certification of individual aircraft or licensing of pilots.

The mission of EASA is to:

- Ensure the highest common level of safety protection for EU citizens.
- Ensure the highest common level of environmental protection.
- Single regulatory and certification process among Member States.
- Facilitate the internal aviation single market and create a level playing field.
- Work with other international aviation organisations and regulators.

The main tasks of the Agency currently include:

- Draft implementing rules in all fields pertinent to the EASA mission.
- Certify and approve products and organisations, in fields where EASA has exclusive competence (e.g. airworthiness).
- Provide oversight and support to Member States in fields where EASA has shared competence (e.g. Air Operations, Air Traffic Management).
- Promote the use of European and worldwide standards.
- Cooperate with international actors in order to achieve the highest safety level for EU citizens globally (e.g. EU safety list, Third Country Operators authorisations).

EASA has its headquarters in Cologne, and an office in Brussels.

10. European Maritime Safety Agency

The European Maritime Safety Agency is one of the EU's decentralised agencies. It provides technical assistance and support to the European Commission and Member States, Iceland and Norway in the development and implementation of EU legislation on maritime safety, pollution by ships, oil and gas installations and ship and port security. It has also been given operational tasks in the field of oil pollution response, vessel monitoring and in long range identification and tracking of vessels.

The Agency was established by Regulation (EC) No 1406/2002 as a major source of support to the Commission and the Member States and subsequent amendments have refined and enlarged its mandate.

The work undertaken by EMSA is supervised by the Administrative Board within which there are representatives of all EU Member States, Iceland and Norway (EFTA countries) and four representatives from the Commission, plus four non-voting representatives from different sectors of the maritime industry.

EMSA is at the core of the regulatory compliance in the maritime sector ensuring the verification and monitoring of the implementation of EU legislation and standards through cycles of visits and inspections. The Agency supports capacity building by providing expertise, training and research, cooperation and tools. The mission of EMSA is to:

- Ensure quality shipping, safer seas, cleaner oceans.
- Improve seafarers' competence, working and living conditions.
- Enhance ship and port facility security.
- Facilitate technical cooperation in the international arena.
- Operate, maintain and develop maritime information operational capabilities, co-operating with Member States and the EU institutions.
- Implement the EU vessel traffic monitoring and surveillance initiatives and provide maritime information services to a wide range of institutional users and different user communities.

EMSA undertakes a number of tasks in certain key areas to meet its objectives by:

- Assisting the Commission in monitoring the implementation of EU legislation relating, among others, to ship construction and planned maintenance, ship inspection and the reception of ship waste in EU ports, certification of marine equipment, ship security, the training of seafarers in non-EU countries and Port State Control.
- Operating the European Union Long-Range Identification and Tracking of Ships European Data Centre and the Union Maritime Information and Exchange System (SafeSeaNet) as well as the International Long-Range Identification and Tracking information data exchange system in accordance with the commitment made in the International Maritime Organisation.
- Providing technical assistance and scientific advice on matters regarding ship safety standards, marine equipment, accident investigation, inspections of classification societies, prevention of pollution by ships in the continuous process of evaluating the effectiveness of the measures in place, and in the updating and development of new legislation.
- Organising training and capacity building activities closely cooperating with the Member States' maritime services and also assisting Enlargement Countries and beneficiaries of the European Neighbourhood Policy.
- Disseminating best practices and promoting sustainable shipping including implementation and enforcement of existing or proposed international and EU legislation and collaborating

with many industry stakeholders and public bodies, in close cooperation with the Commission and the Member States.

- Providing a marine pollution preparedness, detection and response capability, including a European network of stand-by oil spill response vessels as well as a European satellite oil spill monitoring and vessel detection service (CleanSeaNet), protecting EU coasts and waters from pollution by ships.
- Providing number of systems, maintained and developed in order to offer government-to-government maritime information services, including a platform for integrated maritime information services, tailored to user requirements.
- Managing the current requirements and potential developments of the maritime information services and managing the sourcing and day-to-day operations of the Earth Observation data contribution from satellites and remotely piloted aircraft systems to the Agency's maritime information outlook. The ongoing development of the services is triggered through liaising with stakeholders, collecting and translating their business/data requirements into functional specifications. Users include EFCA, EUNAVFOR-Atalanta, EUNAVFORMED-Sophia, Frontex, MAOC-N and Regional Cooperation Programmes.
- Supporting authorities carrying out coast guard functions at national, European and international level by continuing to carry out a host of its core, mainstay activities as well as by setting up new and enhanced services in the field of maritime surveillance and capacity building.

The European Maritime Safety Agency is based in Lisbon.

11. European Fisheries Control Agency

The European Fisheries Control Agency, EFCA, is a European Union body established in 2005 to organise operational coordination of fisheries control and inspection activities by the Member States and to assist them to cooperate so as to comply with the rules of the Common Fisheries Policy, CFP, in order to ensure its effective and uniform application.

EFCA has been established to strengthen the uniformity and effectiveness of enforcement by pooling national means of fisheries control, monitoring resources and coordinating enforcement activities. EFCA coordinates activities in Union and international waters. Operational coordination in Union waters helps to tackle the shortcomings in enforcement resulting from the disparities in the means and priorities of the control systems in the Member States. EFCA also supports the European Union in the international dimension of the CFP and the fight against Illegal, Unregulated and Undeclared, IUU, activities.

The Agency, in cooperation with the European Border and Coast Guard Agency, Frontex, and the European Maritime Safety Agency, each within its mandate, supports the national authorities carrying out coast guard functions. In accordance with Article 3 of Council Regulation (EC) No 768/2005 of 26 April 2005 establishing EFCA, as amended by Regulation (EC) n°1224/2009, the mission of the Agency is inter alia:

- To coordinate fisheries control and inspection activities by Member States.
- To coordinate the deployment of Member States means of control and inspection and to provide additional means (chartering) where needed.
- To assist Member States in reporting information on fishing activities and control and inspection activities to the Commission and third parties.
- To assist Member States and the Commission in harmonising the application of the CFP throughout the EU.
- To contribute to the work of Member States and the Commission on research and development of control and inspection techniques and to provide training and exchange of best practices.
- To coordinate operations to combat IUU fishing in conformity with EU rules.

In order to ensure that fisheries control activities are carried out efficiently and deployment of inspection means is performed in a cost effective way, EFCA has developed a number of applications and tools for Member States and EFCA's own use to support the coordination of fisheries control activities. EFCA is offering applications for sharing and viewing data such as the EFCA electronic reporting system, ERS, the Vessel Monitoring System, VMS, and Fishnet.

In addition, in close cooperation with the European Maritime Safety Agency, EFCA is rolling out the 'EFCA IMS'. This integrated maritime system, which was developed specifically for fisheries control purposes, correlates and fuses Sat-AIS, T-AIS, LRIT, VMS and other fisheries control related information, thus providing an integrated maritime awareness picture. This situational picture is further enhanced with the integration of satellite imagery and vessel detection reporting provided through EMSA's Maritime Surveillance Copernicus services.

All of the applications specified above are very much depending on the availability and accuracy of (space based) PNT information. Experience with the integration of various PNT datasets have indeed shown a certain need for harmonisation and rationalisation of radio navigation services.

EFCA commenced its operations in 2007 in Brussels and was relocated in 2008 to its official seat in Vigo, Spain.

12. European Union Agency for Railways

Following the entry into force of the technical pillar of the 4^{th} EU Railway Package on 15^{th} June 2016, the European Union Agency for Railways, ERA, replaces and succeeds the European Railway Agency.

The mission of the European Union Agency for Railways is “Making the railway system work better for society.” To achieve this, ERA contributes, on technical matters, to the implementation of the European Union legislation aiming at improving the competitive position of the railway sector by:

- Enhancing the level of interoperability of rail systems.
- Developing a common approach to safety on the European railway system.
- Contributing to creating a Single European Railway Area without frontiers guaranteeing a high level of safety.

In addition, ERA will become, from 2019 onwards, the European Authority to:

- Issue single EU-wide safety certificates to railway undertakings.
- Issue vehicle authorisations for operation in more than one country.
- Grant pre-approval for ERTMS infrastructure.

Train navigation and positioning systems based on satellite applications are future components of the Control, Command and Signalling rail subsystem. Accordingly, ERA is setting the rules for their approval, in cooperation with on-going trials brought about by railway operators and the system development, which is taking place under the aegis of Shift2Rail JU, to which ERA is associated.

The European Union Agency for Railways is based in Valenciennes and Lille.

13. Shift2Rail Joint Undertaking

The Shift2Rail Joint Undertaking initiative started in 2009, when key European rail-sector players, under the coordination of the Association of the European Rail Industry, began investigating a policy instrument that could facilitate a step change for the European rail system. The companies supporting Shift2Rail underlined that maintaining the status quo for rail research in Europe was not an option. European leadership of the global rail market could only be maintained if a critical mass from committed EU industry joined forces to develop innovative, high-capacity and high-quality products. Capitalising on the rail sector's success in EU-funded collaborative research projects since the mid-1990s, Shift2Rail constituted a natural evolution from EU industrial research cooperation in Horizon 2020. It was also clear that realising the ambitious EU transport policy and climate change goals required a massive coordinated investment in rail research.

Shift2Rail is the first European rail initiative to seek focused research and innovation and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. Shift2Rail promotes the competitiveness of the European rail industry and will meet changing EU transport needs. R&I carried out under this initiative will develop the necessary technology to complete the Single European Railway Area. Moreover, Shift2Rail has ambitious targets and a robust framework in which to meet them. Specifically, the initiative aims to double the capacity of the European rail system and increase its reliability and service quality by 50%, all while halving life cycle costs.

The members of the Shift2Rail Joint Undertaking are:

- European Union.
- AERFITEC Consortium.
- ALSTOM Transport SA.
- Amadeus IT Group SA.
- ANSALDO STS S.p.A.
- AZD Praha s.r.o.
- Bombardier Transportation GmbH.
- Competitive Freight Wagon Consortium.
- CAF SA.
- DB AG.
- DIGINEXT.
- European Rail Operating Community Consortium.
- Faiveley Transport.
- HaCon Ingenieurgesellschaft GmbH.
- Indra Sistemas SA.
- Kapsch CarrierCom AG.
- Knorr-Bremse Systems für Schienenfahrzeuge GmbH
- MER MEC S.p.A.
- Network Rail Infrastructure Limited.
- Siemens Aktiengesellschaft.
- Smart DeMain Consortium.

- Smart Rail Control Consortium.
- Société Nationale des Chemins de Fer Français Mobilités.
- Swi'Tracken Consortium.
- Patentes Talgo S.L.U.
- THALES.
- Trafikverket.
- Virtual Vehicle Austria Consortium+.

Rising traffic demand, congestion, security of energy supply, and climate change are some of the major issues that the European Union and the wider world are facing. Tackling these challenges will call for the railway sector to take on a larger share of transport demand in the next few decades. The European Commission is working towards the creation of a Single European Railway Area, and has promoted a modal shift from road to rail in order to achieve a more competitive and resource-efficient European transport system. However, rail's share in the European freight and passenger transport markets is still not satisfactory. EU research and innovation must therefore help rail play a new, broader role in global transport markets, both by addressing pressing short-term problems that drain rail business operations, and by helping the sector to gain a stronger market position.

Shift2Rail will foster the introduction of better trains to the market (quieter, more comfortable, more dependable, etc.), which will operate on an innovative rail network infrastructure reliably from the first day of service introduction, at a lower life-cycle cost, with more capacity to cope with growing passenger and freight mobility demand. European companies will develop all this, thereby increasing their competitiveness in the global marketplace. Shift2Rail will also contribute to the paradigm for the modal shift to attract users to rail. For EU passengers, this represents more travel options, more comfort and improved punctuality. For freight forwarder/shippers, rail freight will offer a more cost-effective, punctual and traceable shipment option. Shift2Rail will contribute to:

- cutting the life-cycle cost of railway transport (i.e. costs of building, operating, maintaining and renewing infrastructure and rolling stock) by as much as 50%;
- doubling railway capacity;
- increasing reliability and punctuality by as much as 50%.

Shift2Rail will impact all segments of the rail market: high-speed/mainline, regional, urban/metro & suburban, and freight; it will also make daily life easier for millions of European passengers and rail freight users.

The Shift2Rail Joint Undertaking comprises the following four main bodies:

- The Governing Board, which has the overall responsibility for the strategic orientation and the operations of the Shift2Rail Joint Undertaking and supervises the implementation of its activities.

- The Executive Director, who is responsible for the day-to-day management of the Shift2Rail Joint Undertaking. The Executive Director also manages the Shift2Rail Secretariat.
- The Scientific Committee, which will advise on the scientific and technological priorities to be addressed in the Annual Work Plans. This committee is to comprise world-renowned scientists and provide scientific expertise and science-based recommendations to the Shift2Rail Joint Undertaking. It is appointed by the Governing Board, taking into consideration the potential candidates proposed by the States Representatives Group, the European Rail Research Advisory Council and the European Railway Agency.
- The States Representatives Group, representing EU Member States and countries associated with the Horizon 2020 Framework Programme; inter alia, this group will offer opinions on the strategic orientations of the Joint Undertaking and on the links between Shift2Rail activities and relevant national or regional research and innovation programmes.

14. European Maritime Radionavigation Forum

The EMRF is a forum to represent the views of maritime interests in Europe, to provide expert input to European Policy on safety of navigation and related matters.

The European Maritime Radionavigation Forum gathers different bodies, from maritime administrations to ship owners' organisations, to focus on the coordination of European maritime interests in the field of radionavigation systems for development within Europe.

One of its main aims is to promote the maritime requirements for the safety assessment and certification of future satellite systems, their augmentation systems and back up, and to develop material to achieve recognition and operational approval of those systems as part of the IMO World-Wide Radionavigation System.

15. International Maritime Organisation

The International Maritime Organisation, IMO, is a specialised agency of the United Nations, which is responsible for measures to improve the safety and security of international shipping and to prevent pollution from ships. It is also involved in legal matters, including liability and compensation issues and the facilitation of international maritime traffic. It was established by means of a Convention adopted under the auspices of the United Nations in Geneva on 17 March 1948 and met for the first time in January 1959.

IMO currently has 172 Member States and 3 associated members, 79 international non-governmental organizations in consultative status and 64 intergovernmental organizations which have signed agreements of cooperation with IMO. IMO's governing body is the Assembly, which is made up of all the Member States and meets normally once every two years. It adopts the budget for the next biennium together with technical resolutions and recommendations prepared by subsidiary bodies during the previous two years. The Council, of 40 Member States elected by the Assembly, acts as governing body in between Assembly sessions. It prepares the budget and work programme for the Assembly. The main technical work is carried out by the Maritime Safety, Marine Environment Protection, Legal, Technical Co-operation and Facilitation Committees and a number of sub-committees.

IMO's mission is to promote safe, secure, environmentally sound, efficient and sustainable shipping through cooperation. This is accomplished by adopting the highest practicable standards of maritime safety and security, efficiency of navigation and prevention and control of pollution from ships, as well as through consideration of the related legal matters and effective implementation of IMO’s instruments with a view to their universal and uniform application.

When IMO first began operations, its chief concern was to develop international treaties and other legislation concerning safety and marine pollution prevention. By the late 1970s, however, this work had been largely completed, though a number of important instruments were adopted in more recent years. IMO is now concentrating on keeping legislation up to date and ensuring that it is ratified by as many countries as possible. This has been so successful that many Conventions now apply to more than 98% of world merchant shipping tonnage. Currently the emphasis is on trying to ensure that these conventions and other treaties are properly implemented by the countries that have accepted them.

IMO’s Resolution A.1046(27) specifies the operational requirements for a worldwide radionavigation system, i.e., the accuracy, coverage, availability and integrity levels that a radio navigation system must provide to allow navigation in ocean and coastal waters, and harbour approach and entrance.

16. International Association of Marine Aids to Navigation and Lighthouse Authorities

IALA is a non-profit, international technical association. Established in 1957, it gathers marine aids to navigation authorities, manufacturers, consultants, and, scientific and training institutes from all parts of the world and offers them the opportunity to exchange and compare their experiences and achievements. IALA encourages its members to work together to harmonise aids to navigation worldwide and to ensure that the movements of vessels are safe, expeditious and cost effective while protecting the environment.

IALA has established a number of technical committees of world experts. IALA develops common best practice standards through the publication of Recommendations and Guidelines. This work ensures that mariners have aids to navigation that will meet their needs both now and in the future. Thus, IALA contributes to a reduction of marine accidents, increased safety of life and property at sea, as well as the protection of the marine environment. IALA also encourages cooperation between nations to assist developing nations in establishing aids to navigation networks in accordance with the degree of risk for the waterway concerned. IALA achieves its aim by:

- Developing international cooperation, promoting close working relationships and assistance between members.
- Collecting and circulating information about the activities of its members as well as encouraging, supporting and communicating recent developments.
- Facilitating mutual exchange of information with organisations representing the users of aids to navigation.
- Formulating and publishing appropriate recommendations, standards and guidelines, manuals and other appropriate papers.
- Encouraging IALA members to take into account the development of multi-purpose systems, which may also be used, for instance, to monitor the marine environment.
- Establishing committees, working groups or other such bodies as may be appropriate to study special issues.
- Facilitating assistance to services or organisations requesting help within the marine aids to navigation and allied fields, whether technical, organisational or training.
- Organising conferences, symposia, seminars, workshops and other events relevant to its work.

In ITU-R M.823-3, on the technical characteristics of differential transmissions for GNSS, IALA was assigned the task of coordinating the allocation of identification numbers to radio beacon transmitting stations and reference stations. The identification numbers enable the user equipment to identify the station it is receiving and select particular stations when required. It is essential that the identification numbers avoid duplication and ambiguity. IALA Radionavigation Committee, now called ENAV Committee, devised a scheme to achieve this. IALA also maintains a master list of all relevant characteristics of known DGNSS stations, including identification numbers. Each Administration prepares the input to the master list. IALA has 78 national members, 118 industrial members and 56 associate members. Its headquarters are located close to Paris.

17. International Civil Aviation Organisation

The International Civil Aviation Organisation, ICAO, is a United Nations specialised agency, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation. ICAO works with the Convention's 191 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices, SARPs, and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. ICAO Member States use these SARPs and policies to ensure that their local civil aviation operations and regulations conform to global norms, which in turn permits more than 100,000 daily flights in aviation's global network to operate safely and reliably in every region of the world. ICAO also coordinates assistance and capacity building for States in support of numerous aviation development objectives; produces global plans to coordinate multilateral strategic progress for safety and air navigation; monitors and reports on numerous air transport sector performance metrics; and audits States' civil aviation oversight capabilities in the areas of safety and security.

ICAO's mission is to serve as the global forum of States for international civil aviation.

One of ICAO's strategic objectives is to increase the capacity and improve the efficiency of the global civil aviation system. This strategic objective focuses primarily on upgrading the air navigation and aerodrome infrastructure and developing new procedures to optimise aviation system performance.

ICAO's Council has the authority over the Global Air Navigation Plan, GANP. The latest version of the GANP presents the plans and strategy for the modernisation of civil aviation for the period 2013 – 2028. It is intended to guide regions and states in the preparation of their air navigation plans, with the objective to achieve harmonised and interoperable air navigation systems around the globe. The GANP is reviewed every three years.

An important publication of ICAO related to radio navigation systems is Annex 10 to the Convention on International Civil Aviation, Volume I - Radio Navigation Aids. It gives general provisions and technical specifications for radio navigation aids used in civil aviation.

18. Radio Technical Commission for Maritime Services

The Radio Technical Commission for Maritime Services, RTCM, is an international non-profit scientific, professional and educational organization focusing on all aspects of maritime radio communications, radio navigation, and related technologies. RTCM members are organizations (not individuals) both government and non-government. Although started in 1947 as a U.S. government advisory committee, RTCM is now an independent organization supported by its members from all over the world.

RTCM standards are incorporated by reference into U.S. Federal Communications Commission and U.S. Coast Guard regulations. They have been used as the basis for requirements in standards of the International Electro-technical Commission, which are now mandatory under Chapters IV and V of the International Convention for the Safety of Life at Sea. RTCM is chartered in the District of Columbia, USA.

RTCM has over 130 member organizations, including:

- Manufacturers of radio navigation and radio communication systems.
- Government agencies concerned with standards for maritime radio navigation and radio communication systems.
- Government agencies and commercial entities involved in operation of maritime radio navigation and radio communication systems.
- Associations with an interest in maritime radio navigation and radio communication systems and related public policy.
- Ship owners and operators.
- Educational institutions.
- Sales and service providers.

RTCM members are involved on regional and international maritime radio navigation and radio communication policy issues, regulatory changes, and technical standards development. Its Special Committees provide a forum in which government and non-government members work together to develop technical standards and consensus recommendations in regard to issues of particular concern such as the development of international standards for maritime radio navigation and radio communication systems.

RTCM Special Committees are chartered to address in-depth radio communication and radio navigation areas of concern to the RTCM membership. The output documents and reports prepared by these Committees are usually published as RTCM Standards. Special Committee output documents in the form of RTCM Recommendations have been widely accepted for both voluntary and mandatory use, and the Special Committees routinely update the Recommendations to reflect ongoing changes in technology.

RTCM also contribute to the relevant work of the International Telecommunications Union, the International Hydrographic Organization, the International Association of Aids to Navigation and Lighthouse Authorities, the Comité International Radio-Maritime, the National Marine Electronics Association, and the Mobile Satellite Users Association.

The RTCM Annual Assembly Meeting and Conference is open to both RTCM members and non-members and is structured to provide attendees with an overall update on the changing world of maritime radio communications and radio navigation.

ANNEX 4. Regulatory Framework

Annex 4 presents a summary of regulatory decisions taken since January 2010. The regulatory bodies that have been consulted are mainly the European Commission, the Council, and the European Parliament. Other regulatory decisions from non-European organisations having an impact on EU radio navigation infrastructures and services have been also included for the sake of completeness. The regulatory decisions have been grouped into thematic areas depending on the affected radio navigation services and their application field.

1. EU GNSS Programmes Governance

1.1 Regulation (EU) No 1285/2013 of the European Parliament and of the Council of 11 December 2013 on the implementation and exploitation of European satellite navigation systems.

This Regulation lays down the rules in relation to the implementation and exploitation of the systems under the European satellite navigation programmes, in particular those relating to the governance and the financial contribution of the Union.

The Regulation states the aims of the European satellite navigation programmes, Galileo and EGNOS, including its services and phasing. It underlines that the Galileo programme shall be a civil system under civil control to provide an autonomous global navigation satellite system. It specifies the services to be provided by Galileo: an open service, a commercial service, a public regulated service, and a search and rescue service. The regulation stablishes a development and validation phase to end before December 2013, and a deployment phase to end before December 2020.

Likewise, it is underlined that the EGNOS system shall be a regional satellite navigation system infrastructure monitoring and correcting open signals emitted by existing global satellite navigation systems, as well as the open service signals offered by the system established under the Galileo programme. EGNOS shall provide the following functions: an open service, an EGNOS Data Access Service and a Safety-Of-Life Service.

The Regulation states that Galileo and EGNOS shall be compatible and interoperable with other GNSS and with conventional radio navigation systems.

The Regulation defines the role of the Commission, the European GNSS Agency and the European Space Agency in the governance of the satellite navigation programmes.

The Commission shall:

- Have overall responsibility for the Galileo and EGNOS programmes.

- Manage the funds allocated under this Regulation and oversee the implementation of all programme activities, in particular with respect to their cost, schedule and performance.
- Ensure a clear division of tasks between the various entities involved in the Galileo and EGNOS programmes.
- Ensure the timely implementation of the Galileo and EGNOS programmes within the resources allocated to the programmes.
- Manage relationships with third countries and international organisations.
- Provide to the Member States and the European Parliament, in a timely manner, all relevant information pertaining to the Galileo and EGNOS programmes.
- Assess the possibilities for promoting and ensuring the use of the European satellite navigation systems across the various sectors of the economy.
- Ensure the security of the Galileo and EGNOS programmes, including the security of the systems and their operation.
- Adopt an annual work programme in the form of an implementation plan of the actions required to meet the specific objectives of the Galileo and EGNOS programmes. The annual work programme shall also provide for the funding of those actions.

The European GNSS agency shall:

- Initiate and monitor the implementation of security procedures and perform system security audits.
- Ensure the operation of the Galileo Security Monitoring Centre.
- Perform the tasks provided for in Article 5 of Decision No 1104/2011/EU.
- Contribute to the promotion and marketing of the Galileo and EGNOS services.
- Perform other tasks relating to the implementation of the Galileo and EGNOS programmes, including programme management tasks.
- Enter into the working arrangements with ESA that are necessary for the fulfilment of their respective tasks.
- Provide the Commission with its technical expertise and supply any information necessary for the performance of its tasks.

For the deployment phase of the Galileo programme, the Commission shall conclude a delegation agreement with ESA detailing the latter's tasks, in particular as regards the design, development and procurement of the system. The delegation agreement shall lay down the general conditions for the management of the funds entrusted to ESA. In particular, it shall lay down the actions to be implemented as regards the design, development and procurement of the system, the relevant financing, management procedures and monitoring and control measures, the measures applicable in the event of inadequate implementation of contracts in terms of costs, schedule and performance, as well as the rules regarding ownership of all tangible and intangible assets.

2. Strategy Proposals

2.1 A New Space Strategy for Europe - COM(2016) 705

The proposal for a new space strategy for Europe was presented in a Communication from the Commission to the Parliament, the Council, the European Social and Economic Committee, and the Committee of Regions on 26 October 2016.

In this proposal, it is stated that Europe is a very important global player in space, with activities in all domains: Earth observation, navigation, satellite communications, space research and launchers. Space technologies are indispensable in daily life, and the benefits of space enormous. However, the space context is changing very fast, both in the public and in the private domains. Mega constellations and low-cost private launchers are disrupting concepts representative of the new environment. To keep Europe's leading role in this new space context, the Commission has presented a Space Strategy for Europe. The proposed Strategy has four strategic goals, with numerous mentions to the European navigation programmes:

- **Maximising the benefits of space for society and the EU economy.** Although space generates numerous benefits to daily life, it is still possible to develop further the potential of space. The Commission will encourage the uptake of space services and data. It will take concrete measures when beneficial to include Galileo and EGNOS on new markets, such as mobile phones, critical infrastructures, aviation, the maritime and rail sectors, as well as in the emerging market of autonomous/unmanned vehicles. The Commission will release a European radio navigation plan to facilitate the introduction of GNSS applications in sectoral policies. The Commission commits to the stability of its space programmes. Galileo and EGNOS will develop to keep providing state-of-the-art services, with new capabilities such as authentication and high accuracy. New services may be added to advance the European security and defence capacities.
- **Fostering a globally competitive and innovative European space sector.** The European space industry is facing tougher global competition. Europe needs to maintain and strengthen its world-class capacity to conceive, develop, launch, operate and exploit space systems. The Commission will support the competitiveness of the whole supply change. A priority will be the development of critical space components. Space research should address all segments of the space industrial value chain. The Commission will encourage spinning-in/spinning-off between space and non-space technologies. It will support European space entrepreneurs, start-ups, SMEs, and, in general, the private sector, to develop innovative products and services.
- **Reinforcing Europe's autonomy in accessing and using space in a secure and safe environment.** In the next decade, Europe will launch more than 30 satellites for its Galileo and Copernicus programmes. Consequently, Europe needs to have access to space with freedom and autonomy. It also needs to have access to the required electromagnetic spectrum, and to protect it from interference. Space assets need to be protected from space debris, cyber-attacks and space weather events. Synergies from dual use technologies and systems have to be exploited. The Commission will assess the potential of Copernicus, Galileo and Egnos to meet EU's autonomy and security needs.
- **Strengthening Europe's role as a global actor and promoting international cooperation.** The use and access of space is regulated by international rules and organisations. Space

programmes and technologies are most of the times international by nature. The Commission will promote the international principles of responsible behaviour in outer space. The Commission will contribute to and benefit from international initiatives like GEOSS/CEOS with Copernicus and COSPAS-SARSAT with Galileo. It will promote the development of third-party countries, as it is already doing in Africa with Copernicus and Egnos. The Commission will support European space technologies and expertise in non-EU countries.

2.2 A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility - COM(2016) 766

On November 30th, 2016, the Commission has proposed a new strategy towards the development of Cooperative Intelligent Transport Systems, C-ITS. The pillar of those systems is the availability of connected, cooperative and automated vehicles, which can communicate between them and with the infrastructure. This, in turn, is based on a combination of advanced communication capabilities, on-board situational sensors and navigation systems. The development of autonomous, connected and cooperative vehicles will make transport more efficient, ecological, and safer. It will promote innovation and competitiveness. Vehicles today already present several intelligent capabilities, mainly navigation and on-board situational sensors. In the near future, a new layer will be added to allow communication between vehicles and with the transport infrastructure. This will permit the benefits of cooperation and automation to be realised.

The strategy on C-ITS refers to the Space Strategy for Europe, which underlines the need to integrate space technologies in the transport sector, in particular Galileo and EGNOS. The C-ITS strategy identifies several issues that have to be addressed towards the deployment of services in 2019:

- Priorities for deployment of C-ITS services. The most important factor for the deployment of C-ITS services is their availability across the EU for end-users. It presents a list of Day 1 and Day 1.5 service list. Several of these services may be based on radionavigation services, including navigation into and out of the city, route advice, traffic information and in-vehicle speed limits.
- Security of C-ITS communications. Protection against hacking and cyber-attacks is critical, avoiding fragmented solutions. A common security and certificate policy for C-ITS needs to be developed.
- Privacy and data protection safeguards. Data broadcast from vehicles will be considered personal data, since it can be traced to an identifiable person. Consequently, data will need to be protected by data protection regulations.
- Communication technologies and frequencies. C-ITS services will only be possible using on-board hybrid communication technologies, including 5G and satellite communications. The appropriate radio spectrum frequencies will need to be protected against interference.
- Interoperability at all levels. The systems that compose the intelligent transport network should be interoperable at all levels and across the EU.
- Compliance assessment. Common minimum requirements for C-ITS services need to be defined, after which a full compliance assessment process can be developed.

- Legal framework. An appropriate legal framework governing C-ITS is needed. The legal framework might be based on ITS Directive 2010/40/EU.
- International cooperation. The market of connected, cooperative and automated vehicles is global, so international cooperation is fundamental. This is of interest to public authorities but also to industry. The EU has already cooperated with other international administrations, and must continue to do so in the future.

3. Multi-Modal Transport Networks

3.1 Regulation (EU) No 1315/2013 of the European Parliament and of the Council.

Regulation on European Union guidelines for the development of the trans-European transport network. The Regulation has four main lines of action:

- Establishing guidelines for the development of a trans-European transport network comprising a dual-layer structure consisting of the comprehensive network and of the core network, the latter being established based on the comprehensive network.
- Identifying projects of common interest and specifying the requirements to be complied with for the management of the infrastructure of the trans-European transport network.
- Setting out the priorities for the development of the trans-European transport network.
- Providing for measures for the implementation of the trans-European transport network. The implementation of projects of common interest depends on their degree of maturity, the compliance with Union and national legal procedures, and the availability of financial resources, without prejudging the financial commitment of a Member State or of the Union.

The Regulation identifies priorities for the different transport sectors. Some of these priorities have associated the use of radio navigation services:

- For road infrastructure development, the use of Intelligent Transport Systems in particular multimodal information and traffic management systems, and integrated communication and payment systems.
- For maritime transport infrastructure, implementation of Vessel Traffic Monitoring and Information Systems and e-Maritime services.
- For air transport, supporting the implementation of the Single European Sky and of air traffic management systems, in particular those deploying the SESAR system.

3.2 Decision No 661/2010/EU of the European Parliament and of the Council.

Text with EEA relevance.

This Decision establishes the European Union guidelines for the development of the trans-European transport network, covering the objectives, priorities and broad lines of measures envisaged. These guidelines identify projects of common interest, the implementation of which should contribute to the development of the network throughout the Union. This Decision establishes that the trans-European network shall comprise transport infrastructure, traffic management systems and positioning and navigation systems.

Interestingly, Article 18 of this Decision refers to a future European Radio Navigation Plan. According to this article, the trans-European positioning and navigation systems network shall comprise the satellite positioning and navigation systems and the systems to be defined in the future European Radio Navigation Plan. These systems shall provide a reliable and efficient positioning and navigation service, which can be used by all modes of transport.

4. Civil Aviation

4.1 Commission Implementing Regulation (EU) 2016/1377.

Text with EEA relevance.

This Regulation lays down common requirements for service providers and the oversight in air traffic management/air navigation services and other air traffic management network functions, repealing Regulation (EC) No 482/2008, Implementing Regulations (EU) No 1034/2011 and (EU) No 1035/2011 and amending Regulation (EU) No 677/2011.

Among many other matters, this Regulation establishes the technical requirements for providers of communication, navigation or surveillance services. These requirements include having received training on operating procedures relevant to the provision of communication, navigation or surveillance services in the airspace concerned. Various specialised training programmes covering both terrestrial (e.g., VOR, DF, ILS, MLS, NDB …) and satellite based (i.e., GNSS) radio navigation are specified in the annexes of this Regulation.

4.2 Commission Implementing Regulation (EU) No 716/2014.

Text with EEA relevance.

This Regulation establishes the Pilot Common Project supporting the implementation of the European Air Traffic Management Master Plan. The first Pilot Common Project identifies a first set of ATM functionalities to be deployed in timely, coordinated and synchronised way to achieve the essential operational changes stemming from the European ATM Master Plan.

This Regulation shall apply to the European Air Traffic Management Network and the systems for air navigation services identified in Annex I to Regulation (EC) No 552/2004, which concerns the provision of air navigation services in the single European sky and its main objective is to establish common requirements for the safe and efficient provision of air navigation services in the Community.

4.3 Commission Implementing Regulation (EU) No 1207/2011.

Text with EEA relevance.

This Regulation lays down requirements on the systems contributing to the provision of surveillance data, their constituents and associated procedures in order to ensure the harmonisation of performance, the interoperability and the efficiency of these systems within the European air traffic management network and for the purpose of civil-military coordination.

4.4 Council Decision 2011/209/EU.

This Council Decision endorses the provisional application of the Memorandum of Cooperation NAT-I-9406 between the United States of America and the European Union, which establishes the terms and conditions for cooperation in the promotion and development of civil aviation research and development.

4.5 Commission Implementing Regulation (EU) No 923/2012.

Text with EEA relevance.

This Regulation lays down the common rules of the air and operational provisions regarding services and procedures in air navigation that shall be applicable to general air traffic within the scope of Regulation (EC) No 551/2004.

The set of rules adopted in this Regulation are based upon Standards and recommended practices of the International Civil Aviation Organisation, and all participants in the Single European Sky should adhere to them.

5. Maritime, Inland Waterways Navigation and Fisheries

5.1 Commission Directive 2010/36/EU.

Text with EEA relevance.

This Directive amends Directive 2009/45/EC of the European Parliament and of the Council on safety rules and standards for passenger ships. It adopts and enforces the international conventions, including the 1974 International Convention for the Safety of Life at Sea (SOLAS Convention) and other international codes and resolutions, for the safety rules and standards for passenger vessels. The Directive adopts the changes made to relevant international instruments, such as IMO conventions, protocols, codes and resolutions since the last substantial amendment of Directive 98/18/EC by Commission Directive 2003/75/EC. According to this Directive, passenger ships must keep a record of the equipment that includes, among other items, navigation systems and equipment. In particular, passenger vessels are required to fit a GNSS receiver and an AIS transponder.

5.2 Commission Directives 2015/559/EU, 2014/93/EU, 2013/52/EU, 2012/32/EU, 2011/75/EU and 2010/68/EU.

Text with EEA relevance.

These Directives integrate the various amendments to the international conventions and applicable testing standards in their up-to-date version Directive 2014/90/EU. They also integrate the standards, including detailed testing standards, for a number of items of equipment that have been adopted by IMO and the European standardisation and are considered relevant for the purpose of Directive 2014/90/EU. Such items of equipment are listed in an Annex of this Directive.

The Commission Implementing Regulation 2017/306/EU identifies the items of equipment for which detailed testing standards exist in international instruments, which include, among many other, the following navigation instruments:

- LORAN-C and Chayka equipment
- GPS and GLONASS equipment
- Galileo receiver
- Differential GPS and GLONASS equipment
- Differential beacon receiver for DGPS and DGLONASS Equipment
- Transmitting heading device THD based on GNSS
- Universal AIS transponder
- COSPAS-SARSAT 406 MHz Emergency Position Indicating Radio Beacon instrument
- INMARSAT L-Band Emergency Position Indicating Radio Beacon instrument

5.3 Commission Implementing Regulation (EU) No 909/2013.

According to the Directive 2005/44/EC, River Information Services should be developed and implemented in a harmonised, interoperable and open way. Directive 2005/44/EC envisaged for the EC to set technical specifications for four key technology areas, including:

- The electronic chart display and information system for inland navigation (Inland ECDIS) - No 909/2013.
- For vessel tracking and tracing systems (Inland AIS) - No 415/2007.

The technical specifications for the four key technology areas including Regulations No 909/2013 and No 415/2007 are in the process to be amended to reflect updates to the technical provisions.

Regulation No 909/2013 currently in force sets out technical specifications for the electronic chart display and information system for inland navigation. The regulation includes a section on 'measures to ensure software quality' where it is stated that the inland navigation system shall estimate and display the position of the vessel, fulfilling the following minimal requirements under normal operation conditions:

- The average position estimation shall not deviate more than 5 meters from the true position and shall cover all systematic errors.
- The standard deviation shall be less than 5 meters and shall be based on random errors only.
- The system shall be capable to detect deviations of more than 3σ within 30 seconds.

5.4 Commission Implementing Regulation (EU) No 404/2011.

This Regulation lays down detailed rules for the implementation of Council Regulation (EC) No 1224/2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy.

This Regulation is the most recent of a series of legislative procedures starting with the Regulation (EEC) No 2847/93, that state the Member States' obligation to establish a satellite-based vessel monitoring system for the effective monitoring of fishing activities in their waters. It is considered appropriate to establish common specifications at the EU level for such a system. Such specifications should set out in particular the characteristics of satellite tracking devices (i.e., a unit integrating a GNSS receiver and a satellite/terrestrial communications transceiver), details on the transmission of position data and rules in the case of a technical failure or non- functioning of satellite tracking devices. According to Article 19 of this Regulation, the satellite-tracking device installed on board EU fishing vessels shall ensure the automatic transmission to the Fisheries Monitoring Centre of the flag Member State, at regular intervals, of data relating to:

- The fishing vessel identification.
- The most recent geographical position of the fishing vessel, with a position error which shall be less than 500 metres, with a confidence interval of 99 %.

- The date and time (expressed in Coordinated Universal Time (UTC)) of the fixing of the said position of the fishing vessel.
- The instant speed and course of the fishing vessel.

Moreover, Member States shall ensure that satellite-tracking devices are protected against input or output of false positions and cannot be manually over-ridden.

The Common Fisheries Policy is an example of a use case of GNSS requiring the authentication of the position, velocity and time reported to the Fisheries Monitoring Centre.

5.5 Commission Staff Working Document SWD(2014) 350.

Staff Working Document for the Council Shipping Working Party Recognition of Galileo as a component of the World-Wide Radio Navigation System - Galileo GNSS status update and next steps.

This Staff Working Document was included as an Annex of a draft joint EU submission to the 2nd session of the IMO Sub-Committee on Navigation, Communications and Search and Rescue. The recognition of Galileo as a component of the IMO's World-Wide Radio Navigation System is a key element towards the successful adoption of Galileo in the maritime sector. This proposal underlines the fact that performance standards for Galileo receivers have already been approved by the IMO (MSC.233(82)). Likewise, industry standards for Galileo receivers have already been developed (see IEC 61108-3).

It is stated that Galileo will be able to achieve independently a horizontal accuracy of 4m with a minimum availability of 99.5% over the entire lifetime of the system. This makes the Galileo Open Service suitable for Navigation in Ocean, Coastal, Port Approach and Restricted Waters, and Inland Waterways as per IMO regulation A.915(22) and A.1046(27), with integrity provided by Receiver Autonomous Integrity Monitoring techniques (as per IMO resolution MSC.233(82)). This performance will be further enhanced when considering user equipment processing simultaneously other GNSS. Finally, Galileo may also be used in combination with differential correction techniques to support port operations.

5.6 IMO Report of the Maritime Safety Committee on its 96th Session (31 May 2016).

This IMO Report, in Section 14, includes a recognition of Galileo as a component of the World-Wide Radio Navigation System, following the review of the proposal submitted to the 2nd session of the IMO Sub-Committee on Navigation, Communications and Search and Rescue. The IMO Sub-Committee on Navigation, Communications and Search and Rescue also recognises that the Iridium mobile satellite system could be incorporated into the Global Maritime Distress and Safety System as a service provider.

5.7 IMO Report of the Maritime Safety Committee on its 98th Session (7-16 June 2017).

This IMO Report, in Section 11.12, approved the *Guidelines for shipborne position, navigation and timing (PNT) data processing* to the *Performance standards for multi-system shipborne radio navigation receivers,* developed by the Sub-Committee on Navigation, Communications and Search and Rescue at its fourth session (6 to 10 March 2017).

5.8 IALA Guideline G1129 "The retransmission of SBAS Corrections Using MF-Radio beacon and AIS (Edition 1.0 - December 2017).

This IALA document sets out guidance for marine Aids to Navigation service providers wishing to understand where SBAS information could be used to support the mariner and then how to employ such data. It describes the SBAS use with augmentation services via marine radio beacon and AIS transmissions, considering common SBAS functionality referring to specific SBAS services where required.

Recognizing that the generation of differential corrections can be split from the means of transmission, the documents also provides a number of different example architectures explaining the possible ways to integrate SBAS data into these architectures.

6. Intelligent Transportation Systems

6.1 Directive 2010/40/EU of the European Parliament and of the Council.

Text with EEA relevance.

This Directive establishes the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. According to this Directive, for Intelligent Transport Systems 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 the European satellite navigation programmes, EGNOS and Galileo. This Directive also encourages the use of innovative technologies such as Radio Frequency Identification Devices.

6.2 Regulation (EU) 2015/758 of the European Parliament and of the Council.

This Regulation 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. Therefore, it is appropriate to require its compatibility with the services provided by the Galileo and EGNOS programmes. According to this Directive, manufacturers of the 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. Manufacturers may also choose, in addition, compatibility with other satellite navigation systems.

6.3 Regulation (EU) No 165/2014 of the European Parliament and of the Council.

Text with EEA relevance.

This Regulation repeals Council Regulation (EEC) No 3821/85 on recording equipment in road transport and amends Regulation (EC) No 561/2006 of the European Parliament and of the Council on the harmonisation of certain social legislation relating to road transport. It sets out obligations and requirements in relation to the construction, installation, use, testing and control of tachographs used in road transport. It introduces the second-generation digital tachographs called smart tachographs, which include a connection to the GNSS facility, a remote early detection communication facility, and an interface with intelligent transport systems. According to this Regulation, the use of tachographs connected to a global navigation satellite system is an appropriate and cost-efficient means of recording automatically the position of a vehicle at certain points during the daily working period in order to support control officers during controls, and should therefore be provided for.

This Regulation also states that Intelligent Transport Systems can help meet the challenges faced by the European transport policy, such as increasing road transport volumes and congestion, and rising energy consumption. Standardised interfaces should therefore be provided in tachographs in order to ensure their interoperability with Intelligent Transport Systems applications.

6.4 Commission Implementing Regulation (EU) 2016/799

Text with EEA relevance.

This Regulation lays down the requirements for the construction, testing, installation, operation and repair of tachographs and their components, including:

- Recording of the position of the vehicle at certain points during the daily working period of the driver.
- Remote early detection of possible manipulation or misuse of smart tachographs.
- Interface with intelligent transport systems.
- Administrative and technical requirements for the type-approval procedures of tachographs, including the security mechanisms.

7. Railways

7.1 Directive (EU) 2016/797 of the European Parliament and of the Council

This Directive establishes the conditions to be met to achieve interoperability within the European Union rail system in a manner compatible with Directive (EU) 2016/798 in order to define an optimal level of technical harmonisation, to make it possible to facilitate, improve and develop rail transport services within the Union and with third countries and to contribute to the completion of the single European railway area and the progressive achievement of the internal market. Those conditions concern the design, construction, placing in service, upgrading, renewal, operation and maintenance of the parts of that system as well as the professional qualifications of, and health and safety conditions applying to, the staff who contribute to its operation and maintenance.

Article 19 of this Directive provides a number of requirements to ensure a harmonised implementation of ERTMS in the Union. The European Railways Agency is the appointed authority to monitor and guide this implementation process. ERTMS is the harmonised train control and command system for Europe that will enable the creation of a seamless European railway system, increasing European railways' competitiveness. It has three components: the European Train Control System, an Automatic Train Protection system, and GSM-R, a radio system for providing voice and data communication between track and train.

There are some very strong synergies between ERTMS and the EU satellite navigation systems, Galileo and EGNOS. These synergies will help make rail transport more efficient, more reliable and further improve safety, which are some of the expected benefits of a harmonised implementation of the ERTMS in the Union.

8. Emerging Applications

8.1 Commission Staff Working Document Impact Assessment COM(2015) 613 / SWD(2015) 263

This Staff Working Document presents an Impact Assessment accompanying the proposal for a Regulation of the European Parliament and of the Council on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and repealing Regulation (EC) No 216/2008 of the European Parliament and of the Council. The impact assessment subject of this Staff Working Document identifies the inconsistencies and gaps of the current Regulatory Framework in the field of civil aviation. This initiative is part of the 2015 European Commission's 'Aviation Package for improving the competitiveness of the EU aviation sector'. The objective of this review is to prepare the EU aviation safety framework for the challenges of the next 10-15 years and thus to continue to ensure safe, secure and environmentally friendly air transport for passengers.

Among various other matters, this impact assessment identifies an issue that has emerged recently: the need to regulate the civilian use of drones or unmanned aircraft. One of the technologies that has been suggested to prevent drones or unmanned aircraft from dangerously flying into airspaces such as those near airports is geofencing. Airports and other sensitive areas can be "geofenced", meaning that the satellite navigation instrument and autopilot of the drone know that it cannot fly into these areas.

This study underlines the need to develop EU standards laying down the requirements on the implementation of the geofencing capability. It also suggests that a Regulation covering all types of drones should be envisaged, in order to act coherently and thus prevent that drone operations negatively impact the safety of existing aviation activities.

9. Radio Spectrum Policy

9.1 Decision No 243/2012/EU of the European Parliament and of the Council.

This Decision establishes a Multiannual Radio Spectrum Policy Programme for the strategic planning and harmonisation of the use of spectrum to ensure the functioning of the internal market in the Union policy areas involving the use of spectrum, such as electronic communications, research, technological development and space, transport, energy and audio-visual policies. According to this Decision, Member States and the Commission shall ensure spectrum availability and protect the radio frequencies necessary for monitoring the Earth's atmosphere and surface, allowing the development and exploitation of space applications and improving transport systems, in particular for the global civil navigation satellite system established under the Galileo programme, for the European Earth monitoring programme, for intelligent transport systems and transport management systems.

9.2 ITU

Where spectrum relevant for Galileo is subject of the agenda of an ITU World Radio Communication Conference, the European Union position will be established through a Decision by the Council of Ministers.

10. H2020

10.1 Regulation (EU) No 1291/2013 of the European Parliament and of the Council of 11 December 2013 establishing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)

Text with EEA relevance

This Regulation establishes Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020) and determines the framework governing Union support to research and innovation activities, thereby strengthening the European scientific and technological base and fostering benefits for society as well as better exploitation of the economic and industrial potential of policies of innovation, research and technological development.

The general objective of Horizon 2020 is to contribute to building a society and an economy based on knowledge and innovation across the Union by leveraging additional research, development and innovation funding and by contributing to attaining research and development targets, including the target of 3% of GDP for research and development across the Union by 2020. It shall thereby support the implementation of the Europe 2020 strategy and other Union policies, as well as the achievement and functioning of the European Research Area. The general objective shall be pursued through three mutually reinforcing priorities dedicated to:

- Excellent science.
- Industrial leadership.
- Societal challenges.

Article 19 specifically states that research and innovation activities carried out under Horizon 2020 shall have an exclusive focus on civil applications.

10.2 Council Decision of 3 December 2013 establishing the specific programme implementing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020).

Text with EEA relevance.

This decision establishes the specific programme implementing Horizon 2020, the Framework Programme for Research and Innovation (2014-2020). One of the priority areas of the H2020 Framework Programme for Research and Innovation is the improvement of the mobility of people and freight, which can be achieved through the development, demonstration and widespread use of intelligent transport applications and management systems. According to this Council Decision, new positioning, navigation and timing applications, made possible through the Galileo and EGNOS satellite navigation systems, will be instrumental in achieving this objective.

11. Standardisation and International Cooperation

11.1 Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee COM (2015) 686

This Communication establishes the annual Union work programme for European standardisation. The Regulation (EU) No 1025/2012 enforces the Commission to adopt an annual work programme for standardisation, identifying strategic priorities reflecting the policy objectives set by the Commission in its own planning. The standardisation fields are directly linked to the following Commission's priorities:

- Connected Digital Single Market.
- Resilient Energy Union with a Forward-Looking Climate Change Policy.
- Deeper and Fairer Internal Market with a Strengthened Industrial Base.

Interestingly, among the new actions proposed for 2016, a few of them are related to radio navigation services having the priorities of the EU Space Strategy as legal basis (COM(2011)152), namely:

- Standardisation of location authentication based on the Commercial Service and the Open Service of Galileo. Development of performance standards and associated test procedures to standardise the location authentication. The activities will upgrade the interfaces between elements in the chain, in particular from the GNSS signals to the final location services. The work may address standardisation groups such as OMA, 3GPP, CEN/CENELEC, ETSI, IMO. The deadline to deliver these standards is the 2nd quarter of 2018.
- Standardisation activities for the Galileo Timing Service and the Galileo Search and Rescue Return Link Service. These standardisation activities will address the standardisation of user receiver components including receiver chip, calibration of location timing receivers and processing of GNSS signals to obtain precise timing products. The actions will develop performance standards to standardise timing services provision and will investigate the use of the RLS for remote beacon activation of ELT in aircraft. The deadline to deliver these standards is the 2nd quarter of 2018.
- Access of mobile telephones and other portable radio equipment to Galileo services. Discussion with stakeholders is still on going and it is not envisaged any new standardisation request for 2016.
- On-going action on the continuation of the Update of Galileo standards for multi-modal transport and location- based applications. Continuation of the standardisation in the aviation sector for the introduction of Galileo and the modernised version of EGNOS. Continuation of the update and development of standards for local augmentation systems for Galileo.
- Action started in 2013 on interoperability and Integration of Global Navigation Satellite Systems with Telecommunications Systems for the provision of location based services.
- Under the Directive 2004/52/EC on the European Electronic Toll Service deployment the following further standardisation activities would be beneficial: test standards for the secure monitoring of toll systems and for profiles of information exchange between Service

Provision and Toll Charging activities, and revision of the test standards forming the basis of satellite-based electronic tolling systems and the profile standard for Dedicated Short-Range Communications (DSRC) -based electronic tolling.

- In order to implement new Regulation (EU) No 165/2014 and revised Directive 96/53/EC on Digital Tachographs and on Weights and Dimensions an additional standard on DSRC is needed to allow the transmission of data from a moving vehicle to an enforcement police officer on the roadside, through the DSRC interface.
- Within the field of waterborne transport, technical solutions and standards are based on both European and international requirements. The Commission is considering to issue a standardisation request to the ESOs concerning the development of standards for maritime transport information sharing in support of the e- Maritime initiative and in order to support the implementation of the Directive 2010/65/EU on National Single Windows and electronic transmission of data towards other relevant systems, in particular the Directive 2002/59/EC on Union Maritime Information and Exchange System, SafeSeaNet. In this context a close link with e-Freight, e-Customs and e-Navigation initiatives will be established.
- As regards the modernisation of the European air traffic management network, the ESOs will be requested to review existing standards and their continuation, and to develop, in cooperation with the European Organisation for Civil Aviation Equipment and the European Aviation Safety Agency, future possible activity and the relevant necessary European standards identified in the European ATM Master Plan and in the common projects supporting the implementation of the Master Plan.
- In line with its Communication COM(2013)18 on remotely piloted aircraft systems in a safe and sustainable manner the Commission identified the need to develop a strategy for RPAS at European level. This includes the definition of an appropriate regulatory framework, which could be supported by standards developed by the ESOs or international standardisation organisations, in cooperation with EUROCAE and EASA.

11.2 Commission Staff Working Document SWD (2016) 329.

Commission Staff Working Document laying down the priorities for international cooperation in research and innovation in the framework of the Communication Implementation of the strategy for international cooperation in research and innovation. Among these priorities, there are two areas related to radio navigation services, namely:

- Space research. The EU and Japan have an advanced space S&T sector and a powerful space industry, and there is an EU-Japan Space dialogue as well as long-standing cooperation in research projects. Regarding the satellite navigation system, there could be a real potential for working together in the area of applications (autonomous driving, 3D mapping, rail, agriculture and Global Navigation Satellite System – GNSS - standardisation) receivers and on new services such as the emergency warning service.
- In the area of satellite navigation, the EC-Korea Satellite Navigation Cooperation Agreement, which entered into force on 1 July 2016, foresees the promotion of joint research activities.

11.3 Council Decision 2011/901/EU.

In 2011, this Council Decision adopted an agreement on the promotion, provision and use of Galileo and GPS satellite-based navigation systems and related applications between the European Community and its Member States, of the one part, and the United States of America, of the other part. This agreement concerns the development of a Civil Global Navigation System. This is a follow-on action of the U.S.-EU Agreement on GPS/Galileo Cooperation signed in 2004, which established the principles for the cooperation activities between the United States of America and the European Union in the field of satellite navigation.

This Council Decision endorses the establishment of working groups with experts from both Europe and USA. A working group was established to promote cooperation on the design and development of the next generation of civil satellite-based navigation and timing systems (WG-C). One of the objectives of WG-C is to develop GPS-Galileo based applications for Safety-of- Life services. To this end, WG-C established the ARAIM Technical Subgroup (ARAIM TSG) on July 1, 2010. The objective of the ARAIM TSG is to investigate ARAIM (Advanced Receiver Autonomous Integrity Monitoring) on a bilateral basis. The further goal is to establish whether ARAIM can be the basis for a multi-constellation concept to support air navigation worldwide. Specifically, ARAIM should support en route and terminal area flight; it should also support lateral and vertical guidance during airport approach operations.

LIST OF ACRONYMS

ABAS	Aircraft Based Augmentation System
ADS-B	Automatic Dependent Surveillance-Broadcast
AIS	Automatic Identification System
ANS	Air Navigation Services
ANSP	Air Navigation Services Provider
A-PNT	Alternative Positioning, Navigation and Timing
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
ATC	Air Traffic Control
ATM	Air Traffic Management
CAP	Common Agricultural Policy
CFP	Common Fisheries Policy
CNS	Communications, Navigation and Surveillance
CSDP	Common Security and Defence Policy
DGNSS	Differential GNSS
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
EATMN	European Air Traffic Management Network
EC	European Commission
EDA	European Defence Agency
EDAP	European Defence Action Plan
EDAS	EGNOS Data Access Service
eDLORAN	Differential eLORAN
EEA	European Economic Area
EGNOS	European Geostationary Navigation Overlay System
EGNSS	European Global Navigation Satellite System
eLORAN	Enhanced LORAN
EMRF	European Maritime Radionavigation Forum
EPIRB	Emergency Position Indicator Radio Beacon
ERNP	European Radio Navigation Plan
ERTMS	European Railway Traffic Management System
ETCS	European Train Control System
ESA	European Space Agency

ESSP	European Satellite Services Provider
EU	European Union
FMIS	Farm Management Information Systems
FOC	Full Operational Capability
GBAS	Ground Based Augmentation System
GEO	Geostationary Earth Orbit
GLA	General Lighthouse Authority
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European GNSS Agency
GTO	Geostationary Transfer Orbit
HEO	Highly Elliptical Orbit
IALA	International Association of marine aids to navigation and Lighthouse Authorities
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMO	International Maritime Organisation
IoT	Internet-of-Things
IVS	In-Vehicle System
LBS	Location Based Services
LDACS-NAV	L-band Digital Aeronautical Communications System-Navigation
LEO	Low Earth Orbit
LOA	Length OverAll
LORAN	LOng RAnge Navigation
LPV	Localizer Performance with Vertical guidance
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
Maas	Mobility as a Service
MC	MultiConstellation
MEMS	Microelectromechanical Systems
MF	MultiFrequency
MFF	Multiannual Financial Framework
MLS	Microwave Landing System
MON	Minimum Operational Network
NDB	Non-Directional Beacon

NFC	Near Field Communications
NMA	Navigation Message Authentication
PBN	Performance Based Navigation
PMU	Phasor Measurement Unit
PNT	Positioning, Navigation and Timing
PPP	Precise Point Positioning
PTC	Positive Train Control
RFID	Radio Frequency Identification
R-Mode	Ranging Mode
RNSS	Regional Navigation Satellite System
RPAS	Remotely Piloted Aircraft System
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SBAS	Satellite Based Augmentation System
SAR	Search And Rescue
SES	Single European Sky
SESAR	Single European Sky ATM Research
SoL	Safety-of-Life
STL	Satelles Time and Location
TIS-B	Traffic Information Service-Broadcast
US	United States
VDES	VHF Data Exchange System
VDS	Vessel Detection System
VHF	Very High Frequency
VMS	Vessel Monitoring System
VOR	VHF Omnidirectional Radio range
VRA	Variable Rate Application
WAAS	Wide Area Augmentation System
WWRNS	World Wide Radio Navigation System