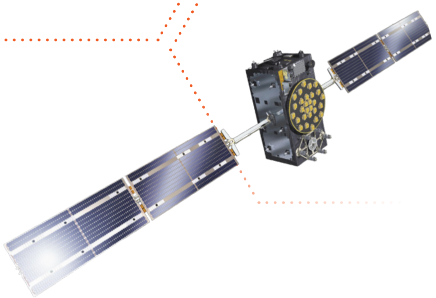

EDITOR'S SPECIAL ON **SPACE DATA FOR EUROPE**

ISSUE 3
2020

GNSS User Technology Report

European
Global Navigation
Satellite Systems
Agency

More information on the European Union is available on the Internet (http://europa.eu).
Luxembourg: Publications Office of the European Union, 2020

ISBN: 978-92-9206-049-7
ISSN: 2467-3854
doi: 10.2878/565013

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HOW TO READ THIS REPORT

The GNSS User Technology Report is a continuously evolving publication that builds upon a similar structure and format used in previous issues. This third issue of the GNSS User Technology Report is therefore structured into the following blocks:

The opening section, **GNSS User Technology Overview**, presents a summary of recent developments and future trends in GNSS. Updates on Galileo, GPS, GLONASS, BeiDou and Regional Navigation Satellite Systems are described in detail as well as latest developments in the area of GNSS augmentation. The chapter also gives a status update on multi-constellation and multi-frequency adoption in receivers. It presents different position processing methods and the latest innovations in signal processing and antenna technologies expected to deliver more accurate, less energy-hungry and more reliable PNT services. Specific focus is made on PNT vulnerabilities that affect GNSS and beyond. Relevant measures and means to get protected against the growing jamming and spoofing threats to GNSS are introduced. The chapter concludes with a description of EU GNSS downstream R&D programmes and examples of innovative technologies from members of Galileo Services organisation.

The second part of the report consists of four sub-sections where technology solutions and their use cases are presented, grouped into four macrosegments.

High-volume devices – presenting devices (meaning chipsets, modules and receivers) manufactured in very large quantities primarily for consumer devices. Automotive (not safety critical), drones (limited to 'open' category according to EASA categorisation), smartphones and specialised IoT devices from mHealth to robotics are all covered.

Safety- and liability-critical devices – presenting devices built in accordance with standards to deliver such solutions. Automotive, rail, aviation, drones (others not belonging to the 'open' category according to EASA categorisation), maritime and search and rescue solutions are all covered.

High-accuracy devices – presenting devices designed to deliver the highest accuracy (position or time) possible. Agriculture, surveying, mining, GIS solutions are all covered.

Timing devices – presenting devices delivering time and synchronisation solutions for the telecom, energy, finance or transport sectors.

In this issue, the **Editor´s special** focuses on **Space Data for Europe**, and the role of flagship European Space Programmes, Copernicus and Galileo. It also provides a vision of major transformations underway within our society and our economy and the benefits that are expected from this digital transformation, including the enablement of the European Data Strategy and Green Deal. The Editor explores the various technologies involved in the exploitation of this massive amount of data, as well as the challenges to fit with and exploit the full potential of up-coming digital age that lay ahead.

Finally, **annexes** close the report with a general overview of GNSS constellations and frequencies (Annex 1), augmentation systems (Annex 2), the definition of key performance parameters (Annex 3), a summary of radio-frequency interference threats to GNSS (Annex 4), the list of acronyms (Annex 5), the methodology used to write this technology report (Annex 6) and information about the authors (Annex 7).

High-volume devices

Safety- and liability-critical devices

High-accuracy devices

Timing devices

FOREWORD

Dear Reader,

I am pleased to write my first foreword to the GNSS User Technology issue 3 in the role of European GNSS Agency (GSA) Executive Director. The GSA's GNSS User Technology Report Issue 3 takes an in-depth look at the latest state-of-the-art GNSS user and receiver technology, along with providing expert analysis on the evolutionary trends that are set to define the global GNSS landscapes in the coming years.

A touchstone for the GNSS industry, academia and policy makers, the report is released at a time of significant changes for the Industry and the EU Space Programme.

The European GNSS Agency is currently in charge of managing operations, service provision, security, market development and user uptake for Europe's Global Navigation Satellite Systems (GNSS), Galileo and EGNOS. Soon, the Agency is slated to become the European Union Space Programme Agency (EUSPA). By providing state-of-the-art, secure services, keeping close ties with the user community and contributing to the latest technology trends and innovations within its projects, EUSPA will continue to serve and support the EU downstream industry including innovators and start-ups with its specific know-how. At the same time, EUSPA will foster synergies at user level with other EU Space Programme components in Earth Observation and Satellite Telecommunications.

The third edition of the GNSS User Technology Report arrives at an important time for GNSS and the Galileo constellation in particular. The GNSS industry is evolving at a rapid pace; new applications emerge, requiring customized, complex receiver technology. Production costs are dropping and an increasing number of dual-frequency receivers become available for mass-market solutions. With numerous players coming from the fields of telecommunications, network operations and IT jumping in the GNSS technology arena, the industry has already understood the potential of Galileo unique features. The future services will reinforce the opportunities to enhance positioning, navigation and timing solutions for businesses and citizens.

The improvement of data technologies is changing the magnitude of data use. This is increasing the capacity to build value-added services. Therefore, in this Editor's special, we focus on the trends and the challenges connected to the data-driven revolution, on the specific space data contribution and on how the EU plans to shape its digital future. Galileo, EGNOS and Copernicus capabilities have a powerful role to play within this new technological shift which will benefit the European Data Strategy and Green Deal.

This publication became possible with contributions from leading downstream industry and SMEs players, including GNSS receiver and chipset manufacturers, and is meant to serve as a valuable tool to support your planning and decision-making with regard to developing, purchasing and using GNSS user technology. We look forward to receiving your feedback and working with you in continuing this exciting evolution.

Rodrigo da Costa
Executive Director

The European GNSS Agency (GSA)
Prague, October 2020

EXECUTIVE SUMMARY

With the recent completion of the BeiDou constellation and forthcoming launches of Galileo satellites, the two new GNSS are expected to reach their full operational capability shortly, increasing the number of global operational systems to four. Meanwhile, the two historical GNSS (GPS and GLONASS) pursue their modernisation, whilst the three regional satellite navigation systems (NavIC, the regional component of BeiDou and QZSS) continue their development adding new navigation satellites in their respective coverage areas. Public augmentation systems follow suit with four new Satellite-Based Augmentation Systems (SBAS) planned to be fully operational by 2023 and upgrade their services to support multiple frequency bands and multiple constellations in the years to come.

The first chapter of the report focus on the **common technology trends** for all types of GNSS devices. The GNSS world that embraced multi-constellation yesterday is now firmly adding multi-frequency to its major trends. As new signals become available from an ever larger number of satellites, GNSS receivers across all domains now commonly feature multi-frequency support in order to deliver better performances to end users, primarily greater accuracy and robustness to interference. The increasing number of open signals in the E5 band mean that E5 is increasingly adopted in new receiver models as the second frequency and today is present in 20% of all receiver models on the market, while L2 adoption decreases. In 2020, the new generation of dual-frequency GNSS receivers is already spreading in the high-volume device macrosegment, and the receivers are being actively developed for traditionally long lifecycle regulated segments such as aviation and maritime.

One of the trends, already observed in the previous edition of the report, translates into a plethora of high-accuracy services now available on the market to all categories of users. Demanding applications such as autonomous vehicles, mobile robots, and outdoor augmented reality benefit from this revolution and trigger this paradigm shift. No longer the exclusive preserve of commercial services providers, high-accuracy services are also proposed by core GNSS (e.g. the free Galileo HAS and the QZSS CLAS) and in the plans of several SBAS service providers.

Moreover, ensuring both safety and security of the PNT solutions remains a key driver of technology developments and innovations. Protection measures against GNSS jamming and spoofing are implemented through different combinations of technologies on both receivers and antennas, through the use of multiple sources of positioning information as well as the authentication of GNSS signals. The Galileo authentication capabilities (Open Service Navigation Message Authentication and Commercial Augmentation Service – OS-NMA and CAS, respectively) are expected to provide good enhancements in this regard.

Lastly, sensors of all types, optical, inertial and others continue to drop in price and increase in performance, and are now routinely integrated with GNSS receivers and their outputs fused. While largely propelled by the emerging world of 'autonomous things', this trend widely benefits other sectors. More than ever, we see GNSS at the heart of a 'metasystem', combining various technologies that support ubiquitous localisation and timing, ubiquitous sensing, and ubiquitous connectivity, where each subsystem contributes to the performance of the others and where the seamless integration of space and ground components is paramount to achieving truly global ubiquity.

In the world of **high-volume devices** for the consumer market, multi-constellation support is now standard and dual-frequency capability is not only a strategic choice for high-end products but gains momentum in smartphone devices.

The introduction of these multi-frequency GNSS devices, the increased use of corrections services, the deployment in some countries of thousands of additional base stations of 5G infrastructure, actively support the democratisation of high-accuracy in the mass market. Combined with the attractiveness of low cost solutions, these benefits are spreading throughout other sectors.

The **safety- and liability-critical devices** domain is traditionally constrained by regulations and standards and therefore slower in adopting new technologies. However, noticeable changes can be observed in the less regulated and lower end part of this sector, which increasingly uses chips from the upper end of the mass market combined with new approaches to support safety-critical applications. While Dual-Frequency, Multi-Constellation (DFMC) solutions have been established in these areas, other mature safety-critical sectors lag behind, pending the finalisation of standards and availability of the first certified receivers. However, the use of multiple frequencies and multiple constellations, augmentation of various types, INS hybridisation, and sensor fusion all contribute to the required 'assured' and safe positioning solutions.

In the professional domain, **high-accuracy devices** reign and steadily evolve towards exploiting all frequencies and constellations as they become available. Modern devices consist of compact sensor-enriched receivers, usually capable of supporting any type of augmentation service (RTK, NRTK, PPP and new PPP-RTK services) and offer flexible customisation by the end user. The continued digitalisation of services, the increased reliance on sensor fusion for fully-connected automated workflow management, and advanced data exploitation techniques supported by AI also generate transformations in the sector. Finally, as high-accuracy geomatics solutions increasingly make inroads into other mass-market sectors, mass-market devices become increasingly able to perform low-end mapping and surveying activities. In that regard, the 'Bring your own device' (BYOD) trend is emerging, whereby surveyors and mappers use their own smartphones as an alternative to proprietary data collection devices.

Lastly, regarding **timing devices** that deliver time and synchronisation solutions for the telecom, energy, finance or transport sectors, research and development efforts have been made at various levels of the timing processing chain. In particular, multi-frequency and multi-constellation adoption as well as innovative Time-Receiver Autonomous Integrity Monitoring (T-RAIM) and interference monitoring algorithms aim to respond to the common demand for improved accuracy, increased resilience and improved availability.

Many of the technical advances observed in this report relate to the exploitation of digital data from GNSS, Earth Observation and from an increasing variety of sources. From the enhancement of industrial processes and transportation paradigms, to the development of a new agriculture or the monitoring of essential climate variables, digital data are already everywhere and benefit both public and private sectors, as well as citizens. The **'Editor's special'** section of this report is devoted to this 'data-driven revolution', which is indisputably changing the world we live in, while meeting technological and societal challenges.

The analysis of GNSS user technology trends is supported by **testimonials** from key suppliers of receiver technology: Broadcom, ICaune, FieldBee, f.u.n.k.e, Google, Hexagon, Microchip, Rokubun, Septentrio, Sony, Trimble, Unifly presenting their latest innovations in the field.

GALILEO PREPARES FOR THE FUTURE

The continued diverging needs of hundreds of applications drive the customisation of GNSS receivers with wide-ranging complexities, capabilities, and resource requirements. The expectations of users in different applications are often contradictory, but they do share some commonalities:

- The need for **continuous and dependable PNT services**, and
- The quest for **ever better performance** at large, e.g. in terms of accuracy, cost, or autonomy.

Thus, with every edition of this report we witness new and innovative products enabled by progress in receiver technology, as well as evolutions in the services proposed by core GNSS and RNSS providers and by public or private augmentation providers.

Indeed, the variety of user requirements calls for a diversity of solutions, both at receiver and system levels. Similarly, the rapid and sometimes unpredictable evolution of these requirements demand a matching evolution of existing services, or the creation of new ones, in a timely manner.

GNSS providers face the challenge of satisfying these emerging needs, without compromising existing services. With satellite lifetimes well in excess of 10 years, the task would be almost impossible, if the original design had not 'planned for the unpredictable'.

This report begins with the presentation of on-going and planned infrastructure evolutions of GNSS and SBAS, which in turn allow for the gradual introduction of new or enhanced services: GPS is now launching its GPS III satellites, GLONASS is switching to the K2 satellites – both moves that will enhance interoperability of the systems – and BeiDou is now focusing on regional services after an impressive effort to rapidly deploy its final constellation. Likewise, Galileo is preparing for the future.

For **Galileo 1st Generation**, this translates into substantial reinforcements of the system's built-in redundancies and resilience and into the introduction of new services and capabilities:

- The OS Navigation Message Authentication and the Commercial Service Authentication;
- Improvements of the I/NAV message, allowing a faster TTFF;
- The High Accuracy Service offering world-wide decimetre level position accuracy.

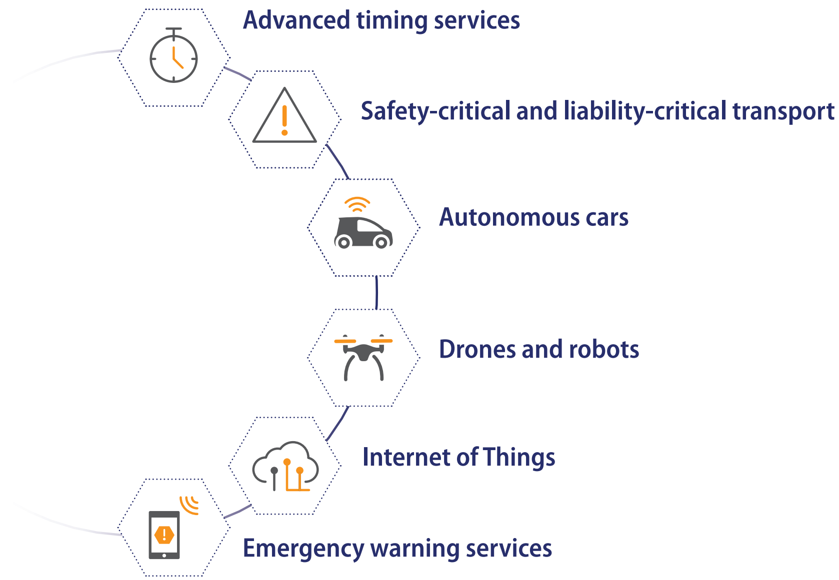
Besides these PNT services, Galileo has been pioneering MEOSAR, notably with the Return Link Service, fully operational since January 2020.

Despite this busy agenda, Galileo already evaluates the feasibility of other services, including an Early Warning Service and an extension of the SAR Return Link Service capabilities, and is fully engaged in the process of developing **Galileo 2nd Generation**. Procurement activities for System, Satellite and Ground Segment will commence in 2020 with the ambitious goal of reaching full operational capability in 2030.

The design of Galileo 2nd Generation is driven by overarching principles, including backward compatibility and the quality of services, but also the absolute need to meet user demands in a timely and effective manner. Acknowledging the changing nature of these user requirements, Galileo 2nd Generation is designed from the onset to evolve incrementally, and with sufficient flexibility to provide new services or signal features, if and when required, without changing the satellites.

The emerging application areas considered include the world of 'autonomous things' (drones, robots and cars), robust advanced timing services, the Internet of Things, safety-critical and liability-critical transport and emergency warning services. Signal evolutions will enable increased user performance (reduced power consumption, faster TTFF, better accuracy, security with authentication, etc.). Along with the evolution of other technologies, such as 5G-powered ubiquitous connectivity or ultra-secure quantum communications, there is little doubt that GNSS – and Galileo – will remain an indispensable utility, continuing to provide users and society with countless benefits.

Emerging applications needs are driving the evolutions of GNSS



GNSS USER TECHNOLOGY OVERVIEW

INTEROPERABLE MULTI-GNSS IS THE REALITY FOR THE FORESEEABLE FUTURE

Continuous worldwide navigation services from multiple constellations

The four GNSS – GPS (USA), GLONASS (RU), BeiDou (PRC) and Galileo (EU) – will continue to provide navigation services with global coverage for the foreseeable future, with more than 100 GNSS satellites in Medium Earth Orbit (MEO). BeiDou-3 satellites have been launched at an impressive rate during 2018-2019, and Galileo 'Batch 3' satellites are due to follow suit from 2021 to complete and maintain the constellation.

Three Regional Navigation Satellite Systems (RNSS), namely the Indian NavIC, the Chinese BeiDou (phase 2, formerly known as Compass) and Japanese QZSS further increase the number of navigation satellites in their respective coverage areas.

Satellite-Based Augmentation Systems (SBAS), such as the European Geostationary Navigation Overlay System (EGNOS), broadcast GNSS-like signals primarily dedicated to the provision of integrity information and wide area corrections, but can also be used as extra navigation signals.

Interoperability of open services for a true multi-GNSS world, with a multi-frequency dimension

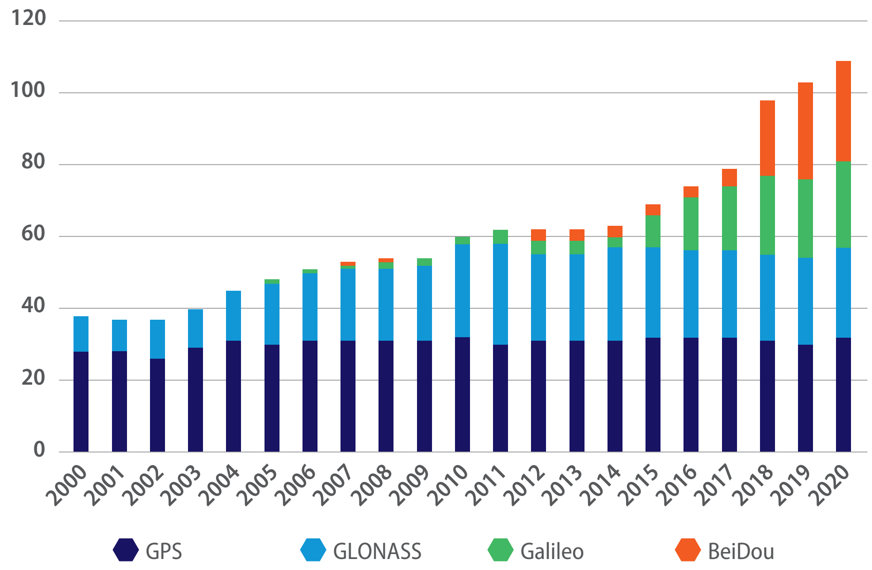
International coordination between GNSS, RNSS, and SBAS providers has led to the adoption of open signals of compatible frequency plans, common multiple access schemes (with GLONASS adding CDMA to its legacy FDMA scheme), and modulation schemes (e.g. Galileo E1 and GPS L1C). This facilitates the design of multi-constellation GNSS chipsets and receivers, to the benefit of end users.

Furthermore, all GNSS and RNSS constellations broadcast open signals in common multiple frequency bands, and SBAS will emulate them with plans to upgrade services to multiple frequencies and multiple constellations in the coming years. The GNSS world that embraced multi-constellation yesterday is adding multi-frequency to its major trends today.

In addition to the baseline interoperable open signals, each GNSS/RNSS provides specific services through dedicated signals and frequencies. This is the case of governmental services[1] such as Galileo Public Regulated Service (PRS) or GPS Precise Positioning Service (PPS), as well as value-added services (e.g. Galileo High-Accuracy Service (HAS), QZSS L6 or BeiDou short messaging service).

1 Not discussed in this report

Operational* GNSS Satellites
MEO only



* Excluding test satellites. Reporting global coverage only (Medium Earth Orbit).

Frequencies: a scarce resource to be protected

All these systems transmit or plan to transmit navigation signals in two common frequency ranges: L5/E5/B2/L3 signals in the lower L Band (1164-1215 MHz) and L1/E1/B1 signals in the upper L Band (1559-1610 MHz). These frequency bands, often referred to by the signal names they contain ('L1 or E5 band'), are allocated worldwide to GNSS on a primary basis and are shared with aeronautical radio navigation service (ARNS) systems.

To allow harmonious development of GNSS and other radio services, the overarching principle underpinning the rules of the International Telecommunication Union (ITU) Radio Regulations is that countries should avoid causing interference to each other's radio services. In this regard, countries operating GNSS determine radio-frequency compatibility with each other, and other systems, using the '1dB criterion' - interference that causes a 1dB rise in the noise floor of a GNSS receiver will degrade its performance and is therefore considered as unacceptably harmful interference.

GNSS AND RNSS INFRASTRUCTURE IS CONTINUOUSLY IMPROVING

All GNSS or RNSS providers strive to improve the quality of the services they deliver, with new capabilities and enhanced coverage being announced. Better performance and higher interoperability will result from these efforts, whilst preserving backward compatibility with existing receivers.

GPS (www.gps.gov)

The USA are currently engaged in an ambitious GPS modernisation programme, which has deployed new satellites (GPS III) since the beginning of 2018. The two first GPS III satellites, named Vespucci and Magellan, have joined the operational GPS constellation in January and April 2020, respectively. They are the first satellites to feature the new L1C signal, almost identical to its Galileo OS counterpart on E1. They also broadcast the legacy L1 and the more recent L2C and L5 signals, resulting in the future availability of 4 civil GPS signals.

The current (Federal Radionavigation Plan 2019) plan states: 'it is expected that 24 operational satellites broadcasting L2C will be available by 2020, with the corresponding ground segment capability available by 2023, enabling transition to L2C by 2023.' and further: 'Civilian users of GPS are encouraged to start their planning for transition now'.

GLONASS (www.glonass-iac.ru/en)

GLONASS-K is the latest generation of GLONASS satellites. The first of these entered into service in February 2016. GLONASS-K satellites transmit CDMA signals (currently at L3 = 1202.025 MHz in the E5 band, but also in future at the L1 and L2 frequencies) in addition to the legacy FDMA signals, and carry a SAR transponder. The previous generation GLONASS-M satellites have been used until 2019 for constellation maintenance, but will be superseded by GLONASS K1 and K2, from 2020 onwards. These satellites also feature improved clock stability, and new control, command and ODTS technologies. In the longer term (post 2025), the current MEO-only constellation could be complemented by 6 additional satellites in Highly Elliptical Orbits (HEO).

BeiDou (en.chinabeidou.gov.cn)

The third generation of the BeiDou system (BDS-3) reached full deployment in June 2020, with 30 satellites (24 MEO, 3 GEO & 3 IGSO) in the nominal constellation, providing global and regional services. The system transmits signals on the B1 (E1/L1), B2 (E5/L5) and B3 (~E6) frequencies. Sharing frequency bands and closely resembling signal waveforms with GPS and Galileo, BDS-3 significantly contributes to the interoperable, multiple GNSS world. BeiDou operates the largest constellation of 30 satellites plus possible in-orbit spares. The regional services include BDSBAS, China's SBAS supporting single frequency and Dual Frequency Multi-Constellation (DFMC) formats and meeting the International Civil Aviation Organization (ICAO) performance requirements, a Precise Point Positioning (PPP) Service and a Regional Short Message Communication (RSMC) Service.

Galileo (www.gsc-europa.eu)

After the declaration of early services on 15 December 2016, Galileo continues its deployment and will start launching its so-called 'Batch 3' satellites in 2021 to complete and replenish its nominal Galileo 1st generation constellation. In parallel, evolution studies are ongoing to prepare the first batch of the Galileo second generation satellites.

In addition to providing a high quality open service based on innovative signals in the E1 and E5 bands, Galileo is also the first GNSS constellation to comprise a SAR capability, including the provision of a return link to users in distress. Galileo also features unique capabilities, such as the provision of Navigation Message Authentication (OS-NMA) and of an encrypted navigation signal on E6, the Commercial Authentication Service (CAS). These functions offer the first protection against spoofing available to civilian GNSS users. Finally, Galileo will provide free access to a High Accuracy Service (HAS) through the use of an open data channel – also on the E6 frequency – used to broadcast high-accuracy augmentation messages.

QZSS (qzss.go.jp/en)

QZSS (Michibiki) has been operated as a four-satellite constellation from November 2018, and three satellites are visible at all times from locations in the Asia-Oceania region, while the current plan is to have a seven-satellite constellation by 2023. The primary purpose of QZSS is to increase the availability of GPS in Japan's numerous urban canyons. A secondary function is performance enhancement, increasing both accuracy and reliability of GPS. QZSS provides a variety of services, from the basic Satellite PNT Service based on the transmission of GPS-like signals, but also an SBAS Transmission Service, a planned Public Regulated Service, a Sub-meter Level Augmentation Service (SLAS), a Centimeter Level Augmentation Service (CLAS) and a variety of other services exploiting the data links of QZSS (e.g. a Satellite Report for Disaster and Crisis Management).

NavIC (www.isro.gov.in/irnss-programme)

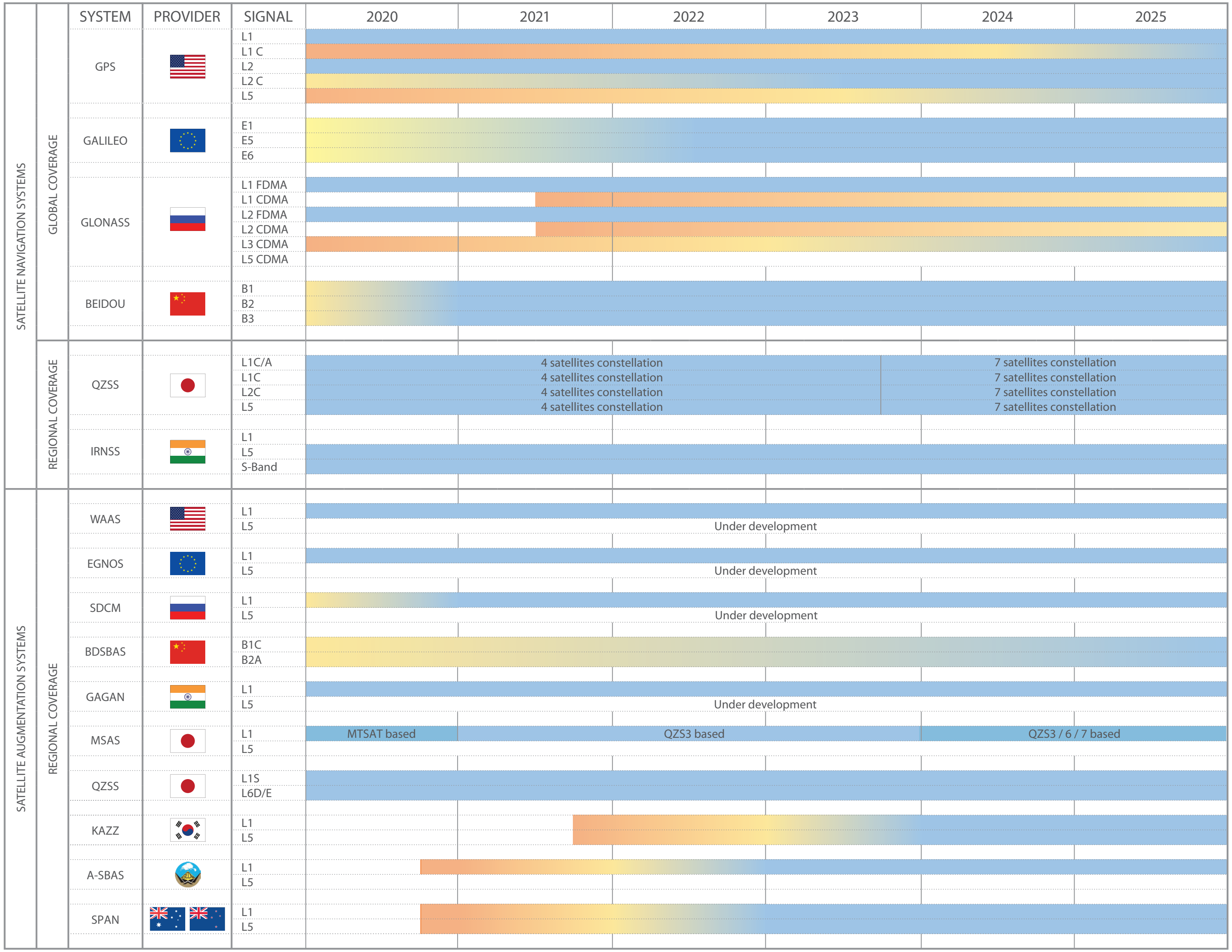
NavIC-1I was successfully launched on 12 April 2018, to increase the NavIC constellation to 7 operational satellites. NavIC covers India and a region extending 1,500 kilometres (930 miles) around it, with plans for a further coverage extension by increasing the number of satellites in the constellation from 7 to 11. NavIC signals consist of a Standard Positioning Service and a Precision Service. Both are carried on L5 (1176.45 MHz) and S band (2492.028 MHz).

MOST SYSTEMS WILL SHORTLY PROVIDE FULLY OPERATIONAL MULTI-FREQUENCY SERVICES

Ground segment updates

GNSS ground segments continuously evolve for better performance, reliability and security. They also need upgrades to support new signals and capabilities brought by the latest generations of satellites, such as GPS III or GLONASS K2. Consequently, whilst Galileo and BeiDou3 are in their first generation, both GPS and GLONASS are modernising their control segments in parallel with the evolution of their space segment.

As an example, the GPS ground segment is being upgraded to the 'Next Generation Control Segment' or OCX. OCX Block 1, providing full operational capability to include control of both legacy and modernized satellites and signals, is expected to be delivered in 2021.



Disclaimer: System deployment plans based upon publicly available information as of July 2020.

Development Plans

The figure on the right shows the current development plans for each satellite navigation system over the next five years. The signal sets and status are reported as follows:

Signal status
- No service
- Initial services
- Full services

THE GALILEO GROUND INFRASRUCTURE ENSURES THE DELIVERY OF HIGH QUALITY SERVICES

The ground segment is an essential and critical component of each GNSS. It consists of a global network of ground facilities that track the satellites, monitor their transmissions, perform analyses, establish the system time, compute the satellite orbits and clocks, and send commands and data to the constellation. As such, its functions can be compared to the role of the brain and nervous system in a human body.

The Galileo ground segment

The Galileo Ground Segment comprises two control centres located at Fucino (Italy) and Oberpfaffenhofen (Germany), a global network of transmitting and receiving stations including Galileo Sensor Stations (GSS), Galileo Uplink Stations (ULS), Telemetry, Tracking & Control stations (TT&C), and a series of service facilities, which support the provision of the Galileo services.

It also comprises a set of Medium-Earth Orbit Local User Terminals (MEOLUTs) serving Galileo's Search and Rescue service.

Galileo ground segment

Image adapted from ESA Navipedia

- **GCC (Ground Control Centre)** – Fucino, Oberpfaffenhofen
- **GRC (Galileo Reference Centre)** – Noordwijk
- **GSC (European GNSS Service Centre)** – Madrid
- **GSMC (Galileo Security Monitoring Centre)** – Madrid, Saint-Germain-en-Laye
- **GSS (Ground Sensor Station)** – Azores, Fucino, Jan Mayen, Kiruna, Papeete, Redu, Réunion, Kerguelen, Kourou, St Pierre et Miquelon, Svalbard, Troll, Wallis and Futuna
- **IOT (In Orbit Test Center)** – Redu
- **LEOPCC (Launch and Early Operations Control Centre)** – Oberpfaffenhofen
- **SAR MEOLUT (Search and Rescue – Medium Earth Orbit Local User Terminal)** – Larnaca, Maspalomas, Réunion, Svalbard
- **SGS (SAR/Galileo Ground Segment)** – Toulouse
- **TGVF (Timing and Geodetic Validation Facility)** – Noordwijk
- **TT&C (Telemetry, Tracking and Control Stations)** – Kiruna, Kourou, Nouméa, Papeete, Redu, Réunion
- **ULS (Uplink Station)** – Kourou, Nouméa, Papeete, Réunion, Svalbard

Introducing The Galileo Reference Centre

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The Galileo Reference Centre (GRC) is a cornerstone of the Galileo service provision. Located in Noordwijk, the Netherlands, the GRC provides the European GNSS Agency (GSA) with an independent system to monitor and evaluate the performance of the Galileo services and the quality of the GNSS signals in space. Monitoring activities are not limited to Galileo but also include the performance of other systems, such as GPS, GLONASS and BeiDou.

The GRC's continuous monitoring of Galileo performance helps the GSA ensure the delivery of high-quality navigation services, so users can better rely on, and benefit from, Galileo. The GRC is fully independent of the Galileo system and of the operator both with respect to the technical solution and operations.

All of the data obtained from the monitoring activities is stored in a centralised archive. This is designed to store service performance data over the entire operational lifetime of the Galileo system. As a result, the GRC has 'big data' to support a number of aspects related to GNSS performance analyses.

For example, the GRC supports investigations of service performance and service degradations, which is of relevance to the Galileo service provision. In addition, the GRC provides GNSS service performance expertise to the Galileo Programme and European Aviation authorities in charge of different aspects, such as aviation network management and safety policies (i.e. EUROCONTROL and the EU Aviation Safety Agency, EASA).

The GRC is the European hub for these kinds of activities, integrating contributions from European national entities, such as research centres, timing laboratories, and national space agencies with its own functionality. The GRC is also the designated European Monitoring and Analysis Centre for Galileo, part of a joint project of the International Committee on GNSS (ICG) of the United Nations that includes contributions from the United States (GPS), Russia (GLONASS) , China (BeiDou), Japan (QZSS) and India (NavIC).

PUBLIC AUGMENTATION SYSTEMS ENHANCE GNSS PERFORMANCE AND MOVE TOWARDS NEW MARKETS

Future SBAS services look to exploit the increased accuracy offered by dual-frequency systems for more demanding applications

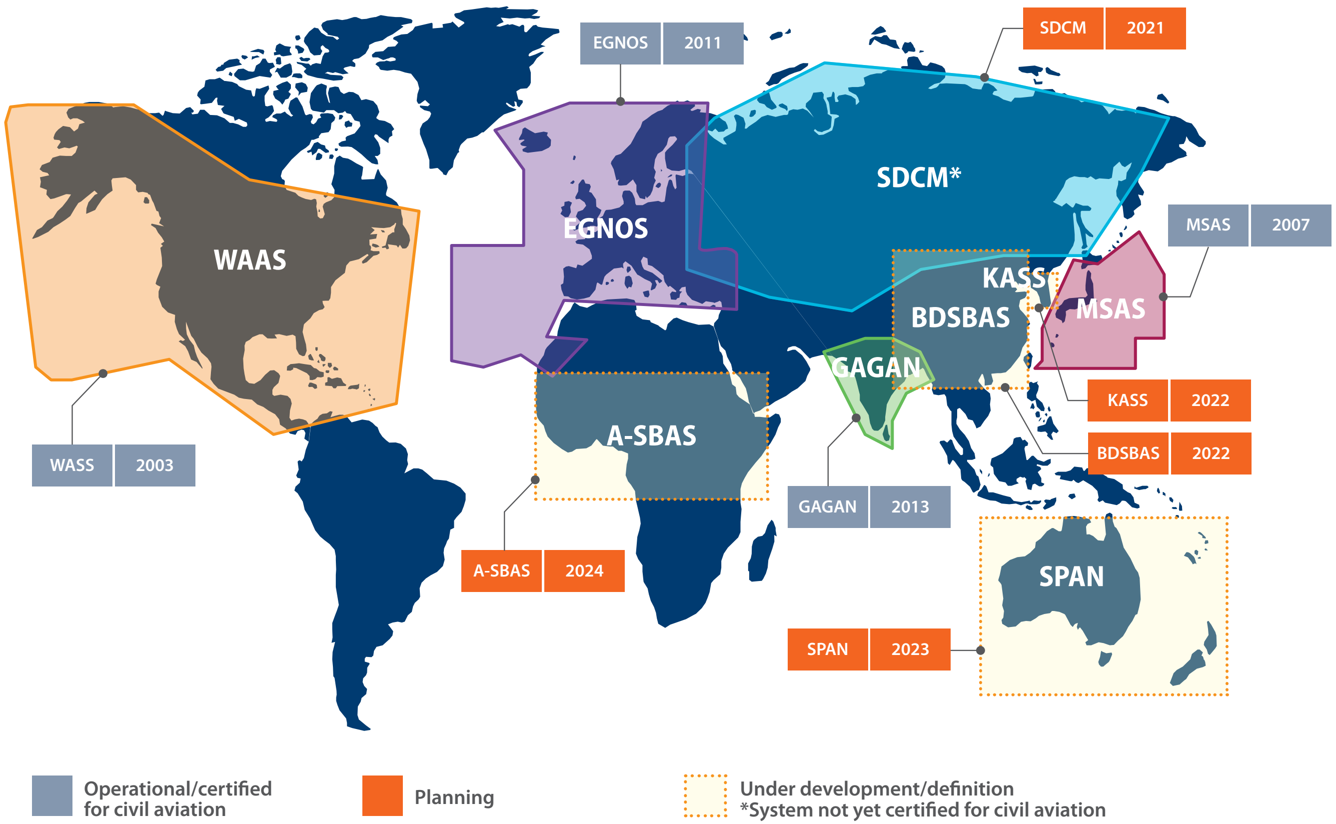
Developed in the 1990's to fulfil primarily the needs of the aviation community, Satellite-Based Augmentation Systems (SBAS) have been widely adopted by many other user segments that require improved accuracy performance, such as agriculture and maritime.

There are four operational SBAS with plans for continued improvements (WAAS (USA), EGNOS (EU), MSAS (Japan), GAGAN (India)) and five additional SBAS in various phases of development (SDCM (RU), BDSBAS (PRC), A-SBAS (ASECNA), KASS (South Korea) and SPAN (Australia and New Zealand)). Whilst the first generation of SBAS systems offers augmentation services to GPS L1, the second generation intends to support both dual- (L1 and E5) and single-frequency (L1) operations, along with supporting correction data for signals originating from multiple GNSS constellations. In Europe, the upgrade of EGNOS (EGNOS V3) will augment Galileo E1 and E5a and GPS L1 and L5 signals from 2025.

The move towards multi-frequency multi-constellation capabilities of future systems will enable greater positioning accuracy, increase availability, and improve robustness to unintentional interference and ionospheric perturbations. These technical evolutions have created opportunities to meet the demand of new markets outside the core aviation sector. Hence, EGNOS, BDSBAS, SDCM, A-SBAS and SPAN service providers consider the possibility of providing value-added services, primarily a Precise Point Positioning (PPP) service, thus targeting the booming 'high accuracy market for all'.

The provision of a PPP service through SBAS is particularly relevant for high-accuracy applications in remote areas with a low density of GNSS reference stations and to serve a higher number of users (a problem of Network RTK). It could support stringent operations of inland waterways navigation, or machinery guidance, to quote only few. An international coordination effort is engaged to ensure that existing GNSS services (particularly safety-of-life services) will not be adversely affected by the move underway.

SBAS indicative service areas



Coordination efforts involve the SBAS Interoperability Working Group (IWG), which comprises the various SBAS service providers, as well as the International Committee on GNSS (ICG), and ICAO Navigation System Panel.

The Annex 2 presents current plans for PPP delivery via SBAS.

5G ENABLES UBIQUITOUS CONNECTIVITY AND CAN CONTRIBUTE TO POSITIONING

The 5G promises

Mobile technology has evolved from a predominantly people-to-people platform (3G) toward people-to-information connectivity on a global scale (4G). 5G is the first mobile system designed to connect everything. 5G is expected to unleash a Massive Internet of Things (MIoT) ecosystem and critical communications applications, where networks can meet the communication needs of billions of connected devices, with the appropriate trade-off between speed, latency, and cost. 5G will be used for:

- **Enhanced mobile broadband (EMBB)** enables real-world speeds of hundreds of Mbps and higher. This delivers much more capacity to efficiently support unlimited data. These improvements to the network will extend cellular coverage into a broader range of structures including office buildings, industrial parks, shopping malls, and large venues, and will improve capacity to handle a significantly greater number of devices using high volumes of data, especially in localised areas.
- **Massive Internet of Things (MIoT)** is enabled by 5G's improved low-power requirements, the ability to operate in licensed and unlicensed spectrum, and its ability to provide deeper and more flexible wide-area coverage. These properties will drive significantly lower costs within MIoT settings and enable the full scale of MIoT.
- **Mission Critical Services (MCS)** drive new market opportunities for mobile technology, including applications that require high reliability, ultra-low latency connectivity with strong security and availability, such as autonomous vehicles, vehicle-to-everything (V2X) applications and remote operation of complex automation equipment where failure is not an option.

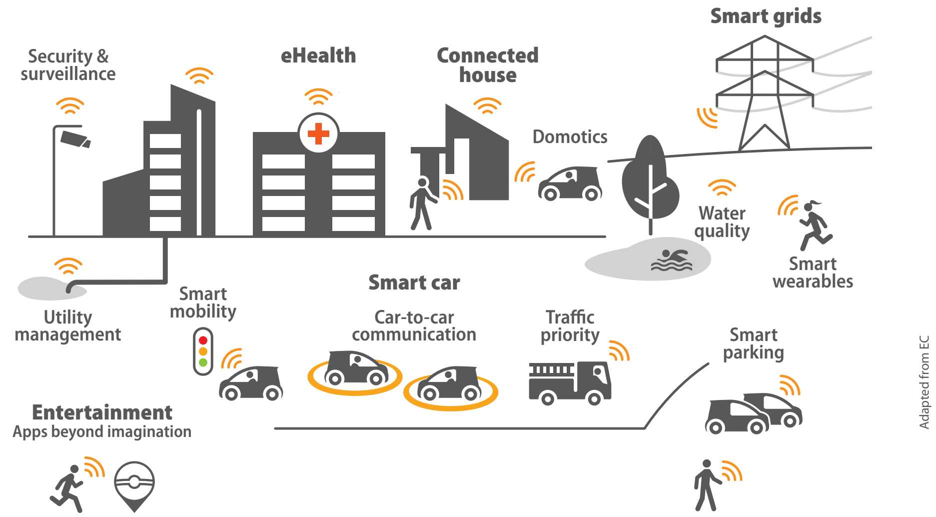
Positioning in 5G

Contrary to existing radio networks where positioning has only been an add-on feature, for 5G mobile radio networks the positioning is seen as an integral part of the system design and will play a key role, enabling a huge amount of different location-based services and applications.

Technologies deployed in 5G networks include a wide bandwidth for better time resolution, new frequency bands in the mm-wave range and massive antenna arrays, which in turn enable highly accurate Direction of arrival (DoA) and Time of Arrival (ToA) estimation especially in direct line-of-sight conditions. This makes 5G networks a convenient environment for accurate positioning, targeting metre or even sub-metre accuracies. This is all the more true as the networks will get denser, e.g. in urban and deep urban environments where GNSS reception is difficult or denied.

Thus, it is expected that hybrid GNSS/5G will be the core of future location engines for many applications in the LBS and IoT domains, with a significantly improved location performance in cities.

Examples of telecommunication applications profiting from 5G



5G, Mobility and Automation

With failsafe wireless connections, faster data speeds and extensive data capacity, 5G can provide the connectivity backbone required to enable cooperative positioning as well as the safe operation of driverless cars, UAVs, mobile robots and, more generally, the world of Autonomous Things.

In the automotive sector, 5G's Mission Critical Services will support 'mission critical' Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and some other Intelligent Transport Systems (ITS) applications, such as the next generation of driver-assisted cars, which will need real-time safety systems that can exchange data with other vehicles and fixed infrastructure around them. This will lay the foundation for driverless cars.

In addition to its trend toward increased automation and autonomy, the transport sector is a significant beneficiary of wireless connectivity in ports, airports, and railways for logistics and digitalisation. The applications here include large-file and real-time data exchange, real-time information, exchange of data from multiple domains (transportation, public administration, emergency services, weather sensing, etc.) requiring connectivity to infrastructure, supported by 5G's MIoT. These large volumes of data need to be accurately synchronised to a common time source to ensure the systems can integrate and prioritise information effectively.

GNSS RECEIVERS CONTINUOUSLY EVOLVE TO OFFER ENHANCED PERFORMANCE

The evolution of receiver design is enabled by technological developments in the semiconductor industry, including increased processing power to support more GNSS channels, and the development of low-cost sensors that allows tighter coupling with different technologies and brings positioning to GNSS-deprived locations.

Simultaneously, market pressures exert a pull towards increased accuracy, improved performance in all environments, reduced time-to-first-fix (TTFF) and robustness against jamming or spoofing. This simplified diagram presents the building blocks of a typical GNSS receiver with its main characteristics (the most important or rapidly evolving of which are highlighted in red).

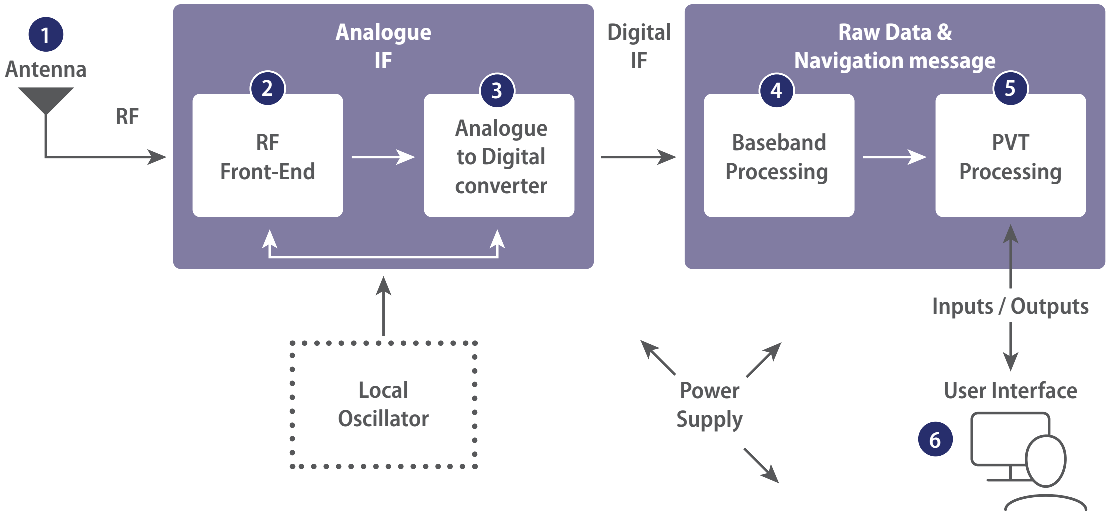
This architecture is typical of a self-contained GNSS receiver. The advent of multi-frequency receivers does not significantly affect this functional diagram, but it does impact several components, notably the antenna (1), the RF front-end (2), and the Baseband processing (4) which are (in a gross approximation) replicated for each frequency.

GNSS receiver functional block diagram

1. Antenna (+ preamplifier)

Receives, amplifies, and band-pass filters GNSS signals.

Dimensions:
- Frequency band(s)
- Active or passive
- Gain
- CSWaP*
- Selectivity
- Noise factor
- Phase Centre
- (Controlled or fixed) Radiation pattern
- Multipath rejection
- Jamming mitigation
- Spoofing mitigation



6. Input/ Output interfaces

Converts data produced in internal formats into recognised formats such as NMEA. After reformatting, the data is output over a suitable data interface such as RS-232, Ethernet, Bluetooth or a combination of several of these. The selection of the interface is often application-domain specific.

2. RF down converter

Down-converts and filters RF signals to an intermediate frequency (IF) compatible with analogue-to-digital converter (ADC)- acceptable input.

Dimensions:
- Input frequency/ies
- Phase noise
- Linearity
- Automatic Gain Control (AGC)
- Isolation

3. Analogue to Digital converter

Converts the analogue IF signal into a digital representation.
Dimensions:

- Linearity
- Number of bits/Dynamic range
- Jitter
- Bandwidth
- Interface to baseband

4. Baseband processing

Acquires and tracks incoming signals, demodulates navigation data.

Dimensions:
- Number of channels
- Signal components processed
- Measurement rate
- Measurement noise (C/N0)
- Continuous vs. snapshot or duty cycling
- Dynamics
- Multipath mitigation
- Interference and jamming mitigation
- Spoofing mitigation

5. PVT (& Application) processing

Computes the estimated position and receiver time offset relative to the constellation's reference time.

Dimensions:
- Solution type (GNSS, DGNSS, RTK, PPP…)
- Sensor hybridisation
- Supported augmentation services
- Single or Multi constellation
- Update rate
- Latency

** Cost, Size, Weight and Power*

THE COMPLEX NATURE OF GNSS SIGNALS REQUIRES SOPHISTICATED PROCESSING METHODS

GNSS signal components are similar for all current constellations

The structure of GNSS signals comprises three main components:

- **Carrier** – sinusoidal electromagnetic waves generated by an oscillator synchronized with an atomic clock on every satellite. Carrier frequencies are chosen in the range 1100-1600 MHz and are used to transmit information (through modulation with spreading codes and data component, when present), and for *carrier phase ranging*.
- **Spreading codes** – seemingly random binary sequences, that can be reproduced in a deterministic manner by intended receivers. They are mainly used to spread the signal spectrum for increased strength, immunity to interference and authorization of the signal usability for public, military, commercial or other services. Codes are typically generated at 1-10 MHz. After de-spreading the signal in the correlator, the GNSS receiver is able to perform synchronization over time and *code phase ranging*.
- **Data component** – low-frequency data streams (e.g. 125 Hz for Galileo I/NAV) containing navigation information: primarily satellite clock and ephemeris data (CED) but also ionospheric correction models, service parameters, integrity and authentication indicators, and other data. Some signals (named 'pilot') are not modulated with data for improved tracking performance.

Different observables provide scalable accuracy levels and services

The PVT solution is computed using either code phase or carrier phase-derived satellite to receiver ranges (so called 'observables'), together with information from the data component and various models for error mitigation. The precision achieved is inversely proportional to the frequency of the processed signal, i.e. high frequency yields high precision. Hence, carrier phase observables typically lead to over 1000 times higher precision than code phase. However, the carrier phase is much more fragile (subject to cycle slips), while code, despite yielding lower precision is more robust.

Carrier phase is used to determine highly precise fractional ranges to the satellites by measuring the phase of the synthetic observable generated in the receiver (a combination of the received signal and internally reproduced replica). Such measurements however provide only fractional (sub one cycle) information, while the integer number of cycles remains unknown. The main difficulty lies in the estimation of the integer number of cycles, in a process called ambiguity resolution.

Code phase is used to measure the delay of the incoming code relative to its local replica, which yields an estimate of the approximate range to the satellite with a precision of up to several metres. Depending on the receiver capabilities, code measurements may be further refined through smoothing with the carrier phase without the need of ambiguity resolution.

Positioning with code-based processing methods generally provides sufficient accuracy, with adequate robustness. Where maximum accuracy is needed, carrier-based processing with centimetre-level accuracy is predominant: the carrier phase is observed through sophisticated receivers, capable of complex multi-frequency combinations with ultimate precision levels.

Errors affecting the observations depend on multiple physical parameters

Satellite errors are mainly caused by residual errors in the Orbit Determination and Time Synchronisation (ODTS) process in the GNSS ground segment, which *predicts* the satellite clock and ephemeris data, and some imperfectly known or modelled errors in the satellite electronics and hardware.

Environmental errors are caused by the ionospheric and tropospheric layers through which the signal passes. The ionosphere modifies the electromagnetic wave's propagation speed in a frequency-dependent manner, while the troposphere generates frequency-independent delays.

Local errors are caused by sources that depend on either the measurement conditions (e.g. signal reflection/multipath and satellite geometry), the quality of the receiver (clock stability, processing noise and hardware biases), the antenna phase centre offset, or variation.

GNSS error components versus mitigation strategies

GNSS satellite		Code based		Carrier based		
		DGNSS (OSR)	SBAS (~SSR)	RTK (OSR)	PPP-RTK (SSR)	PPP (SSR)
GLOBAL (system)	SV orbit error	✓	✓	✓	✓	✓
	SV clock error	✓	✓	✓	✓	✓
	SV bias	✓	✓	✓	✓	✓
REGIONAL/LOCAL (propagation)	Ionosphere	✓	✓	✓	✓	✗
	Troposphere	✓	✗	✓	✓	✗
LOCAL (environment & reciever)	Multipath	Scalability → / ← Accuracy		Scalability → / ← Accuracy / ← Convergence time		
	Receiver errors					
Receiver / user						

Position processing incorporates two major methods for error mitigation

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

More details on the capabilities of these methods are given on page 68.

MULTI-FREQUENCY IS INCREASINGLY USED IN THE PVT METHODS

Major GNSS position computation strategies

Method *	SPP	DGNSS	SBAS	RTK	PPP-RTK	PPP
Observable	Code	Code	Code	Carrier	Carrier	Code / Carrier
Positioning	Absolute (in the GNSS reference frame)	Relative	Relative	Relative	Absolute (in the tracking network reference frame)	Absolute (in the tracking network reference frame)
Comm Link	No	Yes	Yes (GNSS like)	Yes	Yes	Yes
Single Frequency (SF) Dual Frequency (DF) Triple Frequency (TF)	SF or DF	SF	SF current DF planned	Mostly DF	(SF) DF or TF	(SF) DF or TF
Time To First Fix (TTFF)	Rx TTFF	As SPP + time to receive corrections	As DGNSS	As DGNSS + time to resolve ambiguities	Faster than PPP, but slower than RTK	As RTK, but time to estimate ambiguities significantly higher (more unknowns)
Accuracy Horizontal	5-10 m DF 15-30 m SF	< 1 m to < 5 m	< 1 m	1 cm + 1 ppm baseline	< 10 cm	< 10 cm to < 1 m
Coverage	Worldwide	Up to 100s Km	Up to 1000s Km	Up to 10s Km	Regional	Worldwide

** Acronyms are defined in Annex 5.*

Observables condition the available PVT methods

While there exist many strategies to compute a GNSS PVT solution, with accuracies ranging from centimetre level to tens of metres, the choice is constrained by several factors:

- **Availability of the carrier phase observable:** This gives access to the most accurate methods; however the carrier phase is not available in many receiver types, notably those implementing duty cycling or snapshot techniques in mass market.
- **Environmental conditions:** Whatever the receiver capabilities, in some environments where frequent interruptions of the direct receiver to satellite line of sight are present, ambiguity resolution becomes unreliable, rendering all carrier-based PVT strategies unpractical.
- **Availability of the augmentation data:** Except the Single Point Positioning method, all others depend on the timely availability of correction or augmentation data, received through an appropriate communication link. The loss of this communication link may prove to be as detrimental to the solution as the loss of the GNSS signals themselves.

Multi-frequency significantly improves the overall positioning performance

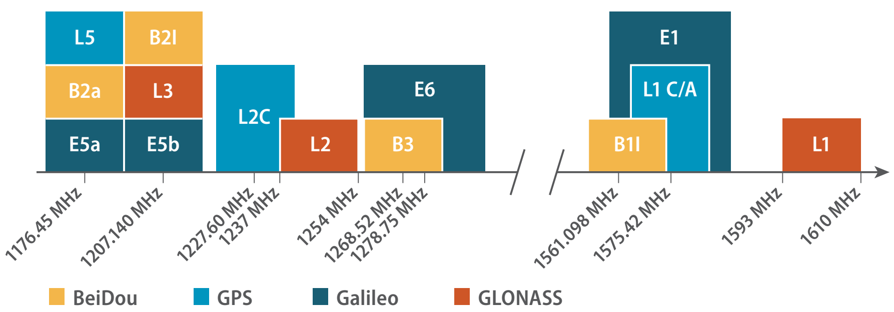
Dual-frequency receivers offer significant advantages over single-frequency receivers in terms of achievable accuracy, but also in terms of improved resistance to interference (owing to frequency diversity). Historically, dual-frequency use has been limited for many years to professional or governmental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

E5 brings a wealth of advantages: being supported by all GNSS and modernised SBAS, these signals will be broadcast on more satellites than any other frequency. Furthermore, this frequency band is shared with the Aeronautical Radio Navigation Service (ARNS) and therefore subject to increased regulatory protection (similar to L1/E1) and suitable for safety critical applications. In addition, signals on E5 benefit from a high chipping rate and of a higher received power than E1/L1 or L2.

In terms of compatible PVT strategies, dual (or more) frequency processing brings even more significant advantages. Despite the *theoretical* single frequency compatibility of all processing methods listed in the table on the left, *in practice* dual frequency is the minimum requirement for carrier phase-based algorithms (RTK, PPP-RTK and PPP).

Triple frequency can further improve the performance of the carrier phase ambiguity resolution algorithms along three characteristics: the maximum separation from a reference station (for RTK and Network RTK), the reliability of the solution, and the time required to obtain and validate this solution. However currently only high accuracy, professional grade receivers have adopted triple or even quadruple frequency processing.

GNSS frequencies in the L band



INNOVATIVE PROCESSING STRATEGIES ENABLE VERY LOW ENERGY PER FIX GNSS POSITIONING

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

Receiver duty cycling: Duty cycling is to power off all the components of a GNSS receiver except those required to react to a location request, thus drastically reducing its power consumption. This technique is currently implemented in virtually all mass market receivers.

Extended and autonomous ephemeris prediction: GNSS receivers consume the most energy during the acquisition phase, covering both the *signal acquisition* and the *navigation message retrieval*. Navigation messages are broadcast by the GNSS satellites at a low transmission rate resulting in long download times (several 10s of seconds), during which the receiver must remain fully powered. To solve this problem, the navigation message can be obtained from alternative sources:

- Either computed by the receiver autonomously, based upon past data, or
- Received via the telecommunication network, possibly with an extended validity to reduce the frequency of the downloads.

Assisted GNSS: GNSS assistance works using the communication network to supply the GNSS receiver with data that will help during the acquisition phase:

- Acquisition assistance data includes coarse timing and Doppler information, used to shorten the power intensive signal acquisition;
- Clock and ephemeris assistance data replace the broadcast navigation message.

A-GNSS minimises the overall GNSS energy consumption by tackling its two main drains, but it comes at the cost of greater demands on the communication link.

Snapshot acquisition: Going forward, snapshot techniques can reduce energy consumption even further as they make it possible to determine the position by using only a minuscule interval of a GNSS signal that is subsequently processed to retrieve pseudorange information and compute the receiver position. For more details on snapshot positioning, please see page 40. These techniques however come at the cost of a reduced sensitivity and accuracy, and a proper balance must be found.

Cloud processing: To further reduce energy consumption, a paradigm shift in the way the position is calculated is required. Instead of performing all GNSS tasks in a single receiver, energy-hungry functions can be 'outsourced' to the cloud, where sufficient energy, processing power and clock and ephemeris data are available in virtually unlimited quantity. This technique comes at the cost of increased demands on the communication link.

LPWAN configurations vs. snapshot techniques

Snapshot configuration	Most proprietary LPWAN	Most cellular LPWAN
Transmission of raw snapshot	✗ Insufficient network uplink	✓
Transmission of pseudoranges	✓	✓
Position determination on device	✗ Insufficient network downlink	✓

Source: GSA

Many of these hybrid techniques impose requirements on the communication network, and are therefore available only with compatible connectivity solutions.

GSA White Paper on IoT Power Consumption

Such technological solutions enable IoT devices to benefit from GNSS positioning performance, whilst remaining compatible with the very long battery life required by many IoT use cases. These are discussed further on pages 39 and 40 of this report.

A more in-depth analysis can be found in the GSA white-paper 'Power-Efficient Positioning For The Internet Of Things: Merging GNSS with low-power connectivity solutions', downloadable from the *GSA website*.

ANTENNAS ARE ESSENTIAL TO GNSS PERFORMANCE

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

Antenna KPIs

There are many possible antenna designs, and those most commonly encountered for GNSS were reviewed in our *GNSS User Technology Report 1*.

Antennas are characterised by frequency range, gain, radiation pattern, noise factor, phase centre definition and stability, polarisation, and multipath and interference rejection, as well as size, shape, electromagnetic and environmental constraints.

Size vs. gain and bandwidth

These characteristics vary greatly depending on the antenna design, and are not independent. For instance, antenna efficiency (or gain) varies with the size of its radiating element(s): the smaller the antenna, the less efficient. This creates challenges for use cases where small size is a binding constraint (e.g. wearables or smartphones), but difficult reception conditions are the norm.

Miniaturisation techniques and innovative designs can be used to reduce antenna dimensions while maintaining an acceptable gain, e.g. by folding the antenna wire or using high permittivity antenna dielectrics. However, a potential drawback is a narrowing of the bandwidth in which the antenna operates most efficiently. Modern GNSS signals have wider bandwidth than legacy signals, which offers a better discrimination between the useful signal and those unwanted. However, this requires antenna bandwidth to match the signal's band, which may not be the case for older models optimised for legacy signals.

The challenge of high performance multi-frequency mass market antennas

Much is said in this report about the benefits of using E5/L5 as a second frequency, including for mass market applications. Among other benefits, signals in this band have a stronger power level than their counterparts in E1/L1. However, this advantage has been observed to be totally lost in some consumer devices, due to antennas with insufficient performance in this band.

Multiple frequency is also an enabler of high-accuracy positioning, which is required to move in the automotive domain to higher levels of automation (ADAS levels 3 to 5). While it can be reasonably assumed that there is more room to accommodate an antenna and ground plane on a car than in a connected watch, other constraints arise: decimetre-level accuracy requires proper multipath protection, continuity requires sufficient gain, and hybridisation e.g. with IMU sensors demands that lever arm effects are duly accounted for, which is only possible when the antenna phase centre is well defined and stable with respect to orientation.

Jamming protection

It is rather common to encounter GNSS signal interference or jamming. Multi element adaptive antennas (also named 'phased array' or CRPA for controlled radiation pattern antennas) are among the most effective interference mitigation techniques that exist. The technology was developed several decades ago, but the early designs were bulky, involved an external Digital Antenna Controller Unit (DACU), very expensive, and reserved for military use. The technology has gradually evolved over time, allowing the design of smaller, self-contained antenna and the availability of products for the civilian users.

© Quantum Reversal

In early 2020, Quantum Reversal – a company based in Calgary, Canada – introduced a new design that processes the CRPA signal in the RF domain, eliminating the need for extensive null-processing electronics. According to the company, this results in very significant cost, size, weight, and power reduction (power reduced from about 15–30 W to around 1 W, size is sub 10 centimetres in diameter versus nominal 15-20 centimetres); while maintaining over 30 dB of interference or jamming rejection. While still a far cry from consumer electronics demands, these reductions might allow CRPA to move into small drones applications, timing networks, transport applications or reference monitoring networks where continuous uninterrupted GNSS service is essential.

Multi-frequency Multipurpose Antenna for Galileo projects

Fundamental Elements

The **GAMMA** project aims to develop a multi-frequency, multipurpose GNSS antenna with multi-stage interference protection based on different detectors, with the scope to tackle different types of interferences. The novelty of the approach is that the antenna is considered a crucial part in defining a strategy for detecting and mitigating interference, not only jamming but spoofing too. The **GAMMA** antenna will present three interfaces: the RF-OUT for professional users with high-end GNSS receiver, Data Serial for professional users to receive and process data, and Bluetooth interface for mass-market applications, exploiting the potential of raw data processing.

The main objective of the **MAGICA** project is to develop a multi-frequency automotive GNSS embedded antenna. The new antenna technology obtained during the project will lead to better equalisation between performance and cost of the GNSS high-accuracy systems to be installed on the vehicle. The target application is autonomous driving where centimetre-level accuracy is a requirement.

MULTI-CONSTELLATION IS THE NORM IN TODAY'S RECEIVERS

The evolution of constellation support in GNSS receivers follows the evolution of the space infrastructure, with a delay approximately corresponding to the product lifecycle. As a result, manufacturers now address all constellations in earnest, which has led to a dramatic increase in support for multi-constellation capabilities across the whole market.

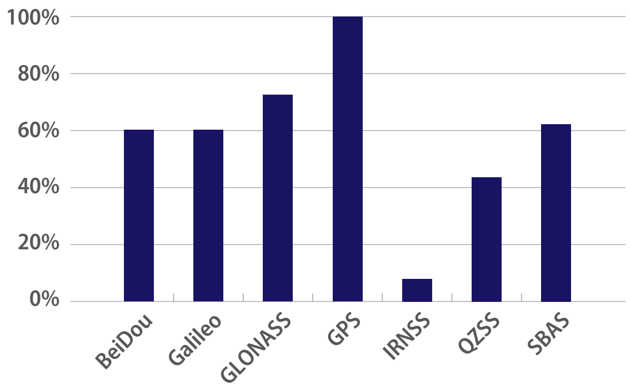
The vast majority (76%) of current receivers are multi-constellation, and the most popular way to provide multi-constellation support is to cover all constellations, which represents 52% of receivers, an increase of 20 percentage points (p.p.) over the last 2 years. This trend is mainly fuelled by increased Galileo and BeiDou support (~ +20 p.p.). GLONASS, QZSS and NavIC also show increased support, although to lesser extent.

The legacy use of single or dual GNSS (GPS/GPS+GLONASS) is reserved for applications with stringent power limitations or low performance requirements, or where regulations have not yet been updated to multi-constellation.

Multi-constellation is by far the preferred configuration owing to the benefits, it brings to receiver performance, particularly in environments with constrained view of the sky such as urban canyons. The range of benefits includes:

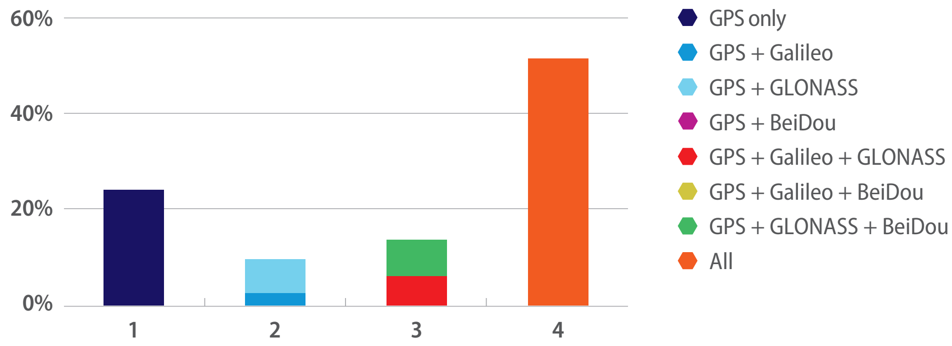
- **Increased availability*** – particularly in the aforementioned constrained environments, where shadowing would prevent a single constellation from providing an adequate, or in some cases any, solution.
- **Increased accuracy*** – better geometry, and more signals which allow the receiver to reject compromised inputs (e.g. from multipath).
- **Improved robustness*** – several independent systems are harder to spoof than a single source.

Constellation capability of GNSS receivers[1]



[1] shows the percentage of receivers capable of tracking each constellation

Supported constellations by GNSS receivers[2]



[2] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 GNSS constellations

Analysis of GNSS receivers' capabilities

The GSA's independent analysis assesses the capabilities of almost 500 receivers, chipsets and modules currently available on the market (end of Q1 2020). For the analysis, each device is weighted equally, regardless of whether it is a chipset or receiver and no matter what its sales volume is. The results should therefore be interpreted as the split of constellation support in manufacturers' offerings, rather than what is in use by end users.

Disclaimer: The above charts reflect manufacturer's publicly available claims regarding their product's capabilities and judgement on the domains to which they are applicable. Use in actual applications may vary due to issues such as certification, implementation in the end user product, and software/firmware configuration.

** The Key Performance Parameters are defined in Annex 3*

MULTI-FREQUENCY BECOMES COMMON IN MOST DOMAINS

As new signals become available from an increasing number of satellites, receivers beyond the traditional high-accuracy applications now feature multi-frequency support for better performance. Second generation dual-frequency receivers for the mass market became available in 2020, and are being actively developed for traditionally long lifecycle regulated domains.

The primary driver beyond this trend is the increasing number of open signals in the E5 band, already outnumbering those in L2 (the legacy choice for a second frequency), and their adoption in many receiver models.

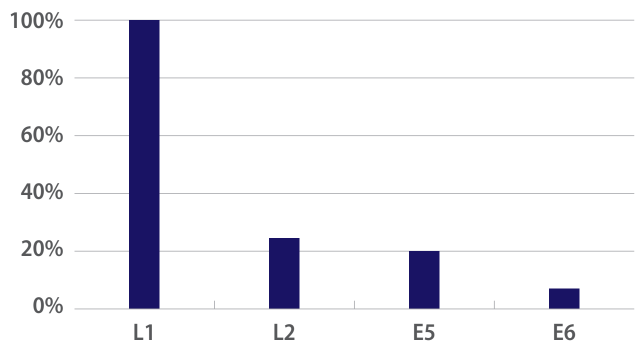
This has resulted in a steady increase in production of receivers that support E5 over the last two years, and reduction in those that support L2. In the current transition period (E5a/L5 signals rapidly outnumber those in L2), several dual frequency mass market chipsets offer a configurable second frequency (either L2 or E5) that is selected by the customer when placing the order.

In the interest of simplicity, we report frequency capability at the frequency band level, namely the L1, L2, E6 and E5 bands. As shown on page 18 and in Annex I of this report, there are multiple signals or signal components present in each of these bands, which may be fully or partially exploited according to the receiver manufacturers' strategy.

As an example, for Galileo E5 only, one can use the E5a (BPSK), E5b (BPSK), and E5a+b (AltBOC) signal components, or any combination thereof. Whatever the case, such a receiver will be reported as 'E5 capable'.

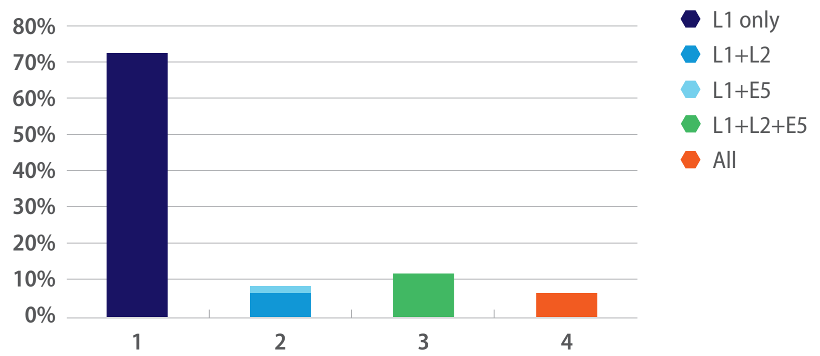
The chart below represents the current (2020) preferred choices of frequency bands. As previously noted, some products are reported as triple frequency (L1+L2+E5), based on claimed capability; while they are delivered to the customer as dual frequency. This results in an artificial decrease of dual frequency products, and corresponding increase in those with triple frequency capabilities.

Frequency capability of GNSS receivers[1]



[1] shows the percentage of receivers supporting each frequency band

Supported frequencies by GNSS receivers[2]



[2] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 frequencies

Analysis of GNSS receivers' capabilities

The GSA's independent analysis assesses the capabilities of almost 500 receivers, chipsets and modules currently available on the market (end of Q1 2020). For the analysis, each device is weighted equally, regardless of whether it is a chipset or receiver and no matter what its sales volume is. The results should therefore be interpreted as the split of frequency support in manufacturers' offerings, rather than what is in use by end users.

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** The Key Performance Parameters are defined in Annex 3*

PNT VULNERABILITIES: GNSS AND BEYOND

The security of PNT-based applications must be ensured at all stages

GNSS vulnerabilities are now commonly acknowledged, and widely described e.g. in previous editions of this report. However, for users who entrust their safety or security to PNT-based systems or applications, the trust or confidence goes beyond GNSS and must encompass the end-to-end-application, which is only as safe or secure as its weakest component. This need for an overall 'trust perimeter' is schematically described in the figure on the right.

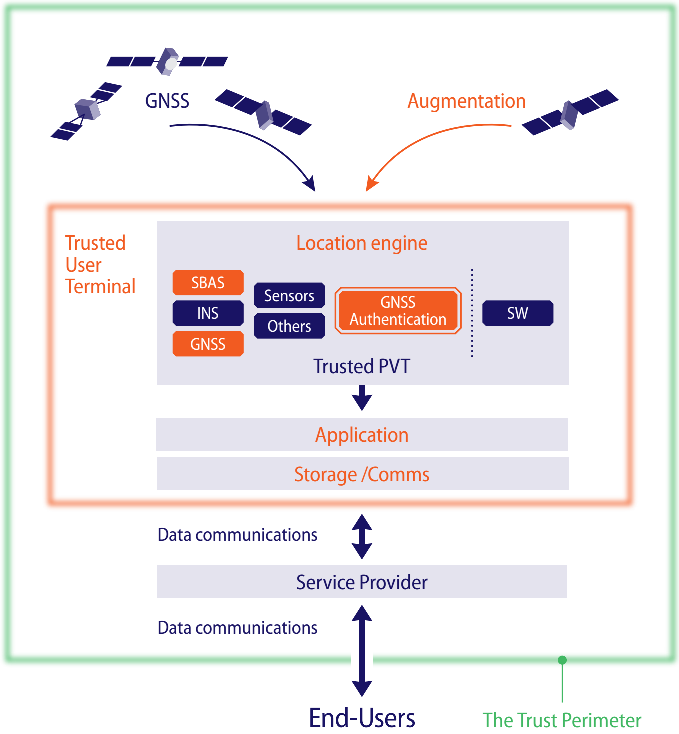
As immediately apparent, GNSS is but one component in a complex system, and not necessarily the easiest to attack for maleficent actors: It might be easier or cheaper to hack the output of a receiver to report fake positions than to spoof the incoming GNSS signals. This is e.g. how maritime AIS can report positions thousands of miles away from the vessel's true position: out of reach of any spoofer, the non-secure communication link is the 'point of attack'. Thus, GNSS authentication is a necessary building block of the overall application security, but not the only one.

Appraising the jamming and spoofing threats

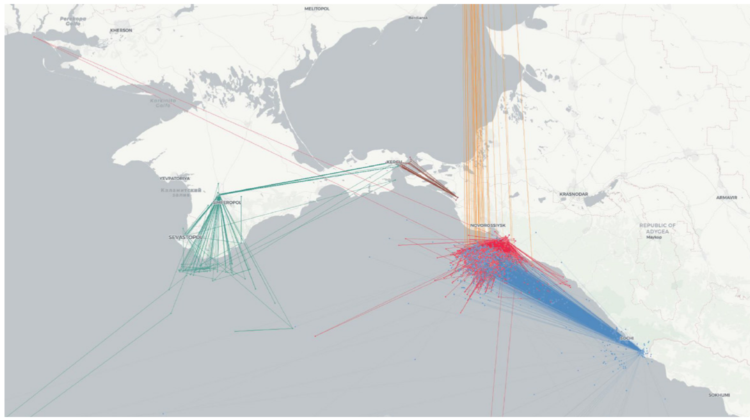
GNSS **jamming** incidents are reported in very large numbers, the vast majority of them caused by so-called 'privacy protection devices' (illegal in most countries). A wide variety of tools allow the detection, classification, and even geolocation of jammers. These include both terrestrial and space-based means, as recently demonstrated by researchers at the University of Texas at Austin[1]. However, no internationally coordinated effort to deploy jamming monitoring means or to prosecute offenders exist as yet. This is in spite of the extent of potential damages.

GNSS **spoofing** (including **meaconing**[2]) incidents are less frequently reported, but they are increasing in number, and spectacular. The explanation for the lower numbers is that successful covert spoofing attacks are not detected or not reported by their victims for security reasons. Regarding the growing number of detected spoofing attacks, it must be noted that these are of a new type: the culprits apparently do not attempt to be covert, but to deny GNSS usage. Indeed, as stated by the University of Texas at Austin researchers *'spoofing is more efficient for denial of service than jamming: a 1 watt spoofer is more potent than a 1 kilowatt narrow/wideband jammer at the same stand-off distance'.*

The trust perimeter



The 'trust perimeter' of a typical LBS application contains many interconnected building blocks. Every block and connection is contributing to the overall security, or lack thereof.



The widely reported 'Black Sea' spoofing, effectively resulting in the loss of GNSS services over the area. The coloured lines show ships positions jumping from truth to the location of certain airports.

A rather crude 'GNSS repeater' as freely marketed for providing seamless indoors coverage could actually spoof all GNSS receivers in the vicinity of its own position, if used improperly.

1 'GNSS Radio Frequency Interference Detection from Low Earth Orbit', INC 2019, Edinburgh
2 Relevant definitions are given in Annex 4 page 100

PROTECTING AGAINST GNSS JAMMING AND SPOOFING AT ALL LEVELS

Ensuring a clean RF environment

The very first layer of protection for GNSS users is ensured by the use of frequency bands allocated by the International Telecommunication Union (ITU), the specialised agency for information and communication technologies of the United Nations; as specified in its Radio Regulations (refer to page 10 and to Annex I of this report for GNSS frequencies). However, enforcement of these regulations remains a national responsibility, which is unequal across countries.

Authenticating the GNSS signals

GNSS authentication is achieved by incorporating specific features that cannot be predicted or forged by malicious actors in the broadcast signals. A receiver enabled for authentication can interpret these features in order to distinguish genuine signals from imitations. This can be done at two complementary levels: at the data level, to authenticate the broadcast navigation messages; and the range level, to authenticate the measured ranges to the satellites. As of 2020, only Galileo has committed to deliver such features for the general public, as described on the next page. Authentication can protect against spoofing, but not against jamming.

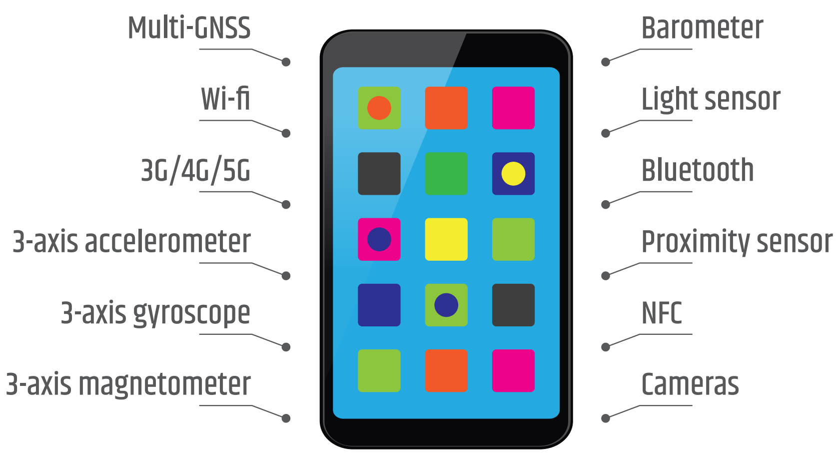
Using multiple sources of positioning information

It is proper navigation practice never to rely on a single source of information and to always cross-check it with independent measurements. For GNSS users, this translates into using multiple constellations, and possibly multiple frequencies. However, in many cases this is necessary, but not sufficient to ensure the proper availability, continuity, reliability and overall performance of the PNT solution. GNSS is therefore complemented by other technologies, which are varying according to the intended use, performance and constraints. As an example, smartphones (the most numerous GNSS receivers) typically contain many sensors than can be used to provide redundant positioning or movement information (see figure on the right, and refer to page 26 for a discussion on complementary technologies).

Paradoxically, all these embedded complementary PNT technologies mean that consumer devices may be more resilient than high grade, professional, but GNSS-only receivers.

Using a better antenna set up

As discussed on page 20, adaptive antennas (CRPA) can be a very efficient tool against jamming. But simpler configurations (2 antennas) can provide direction of arrival information, which is very useful in detecting incoming spoofing signals (ref. e.g. Dr Brad Parkinson 'GPS for humanity' conference of 7 Jan 2020).



A typical smartphone embeds a wealth of sensors that can be leveraged to ensure reliable positioning.

Implementing dedicated receiver techniques

Receiver methods are based on the signal power or carrier to noise density ratio (C/N0) monitoring, time of arrival (TOA) discrimination, distribution checks of correlator outputs and consistency checks among different measurements such as ephemeris data, clock offset change or code and carrier Dopplers.

Signal Quality Monitoring (SQM) techniques, originally designed for multipath detection and waveform deformation monitoring, can be used to identify the deformation on the correlation function of a typical spoofing attacks. The challenge for spoofing detection and rejection is to discriminate between true signals and unwanted signals. Multipath detection has the same objective and similar techniques are therefore proposed.

Novel innovative approaches to the correlation process, such as the 'Supercorrelator', claim the capability to separate line of sight and non-line of sight signals during the correlation process, providing multipath mitigation, anti-spoofing and signal arrival-angle determination.

As powerful as they are, such methods are currently (2020) implemented only in sophisticated high grade receivers, but not widely available in other GNSS chipsets.

GALILEO AUTHENTICATION CAPABILITIES COME ONLINE

Galileo authentication capabilities (OS-NMA and CAS) have been added to the original system design to respond to the user need of anti-spoofing capabilities, due to the growing spoofing threat. This user pull has been balanced with a need to minimise changes to the Galileo core infrastructure and limit the impact on the users' receivers. Furthermore, the design has been driven by the need to ensure backward compatibility for Galileo users.

OS-NMA for data authentication

OS-NMA is a free additional capability of the Galileo Open Service (OS), that is going to be available worldwide. It authenticates data for geolocation information through the Navigation Message (I/NAV) broadcast on the E1-B signal component. This is achieved by adding authentication-specific data (mainly message authentication codes (MACs) and keys, plus additional data for configuration purposes) in previously reserved bits of this message. OS-NMA follows a protocol known as TESLA (Timed Efficient Stream Loss-Tolerant Authentication), which only requires public keys to process the OS-NMA data, avoiding the need to securely store private keys in the receivers.

Using only spare fields of I/NAV, OS-NMA does not introduce any overlay to the system, thus the OS navigation performance is untouched. Furthermore, as OS-NMA is designed to be fully backward compatible, standard OS receivers can continue to ignore the dedicated OS-NMA fields of I/NAV and keep functioning with the same performance level. Only OS-NMA ready receivers will decode these fields and be able to authenticate Galileo navigation data.

As depicted in the figure on the right, an OS-NMA capable receiver differs from a generic OS receiver only by the additional firmware/software required to:

1. Retrieve the MACs and Keys fields in the navigation message;
2. Process these data in the TESLA cryptographic chain to confirm whether data is authentic.

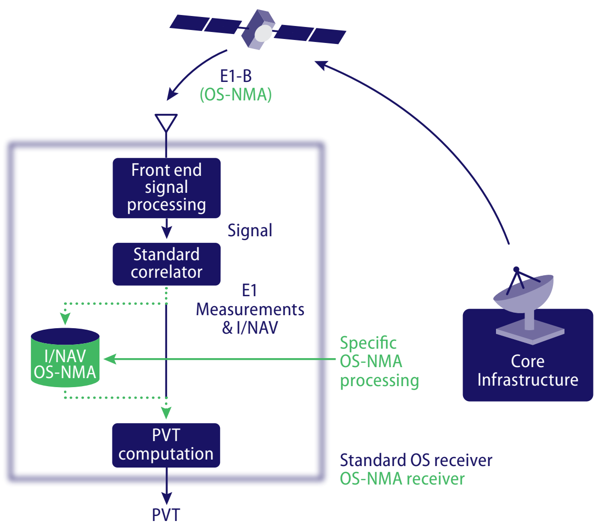
In particular, no extra hardware is required as long as the receiver has access to loose time synchronisation, and the extra computational burden remains commensurate with low-cost receiver capabilities. Furthermore, the receiver only needs a public key, which can be updated when necessary through an OTAR (Over The Air Rekeying) mechanism.

CAS for ranging authentication

CAS (Commercial Authentication Service) is a ranging authentication function implemented by encrypting the spreading code (SCE Spreading Code Encryption) of the E6C (pilot) channel with a secret key. To perform E6C range measurements, the receiver needs to know (at least part of) the secret spreading code. To ensure backward compatibility, CAS is based on the only civilian signal including cryptographic features (E6).

When using both OS-NMA and CAS, users will benefit from data (navigation message) and range authentication, allowing PVT authentication.

OS-NMA principle of operation



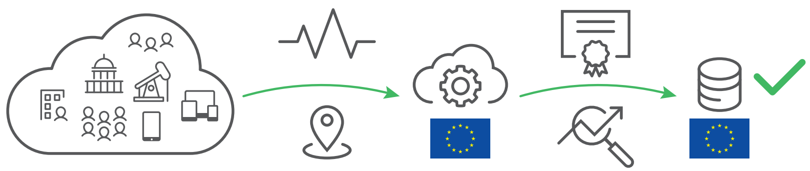
Development of an advanced interference detection and robustness capabilities system

Fundamental Elements

In 2020 the GSA issued an invitation to tender with a view to establish a new interference detection mechanism at receiver and antenna level based on crowdsourcing. A system to share information sourced from a specified set of user communities will be defined and developed.

The planned activities will identify and engage with contributors (e.g. entities currently monitoring vast networks of devices with GNSS receivers, such as insurance, car rental, taxi, and fleet-management or logistics services companies). The enrolment scheme must ensure the provision of data either through self-selection of users or incentives to share information. The objective is to maximise the granularity and coverage area of the monitoring network.

The project will also establish a scheme to protect privacy and confidentiality of all data provided by the users to the system; without the system sharing back any sensitive information. Likewise, major interference events shall be promptly communicated to the public spectrum authorities of the EU Member States. Contract signature is expected by the end of 2020.



INERTIAL NAVIGATION AND GNSS ARE IDEAL COMPLEMENTS

Among all non-GNSS positioning technologies (see e.g. the GSA User Technology Report issue 1 for an overview), inertial navigation occupies a special position, not only because it is ubiquitous, like GNSS, but also because it offers characteristics that make these two technologies natural complement of each other, and ideal candidates for integration:

GNSS	Inertial Navigation System (INS)
Absolute position fixing	Orientation and relative positioning
Outdoors	Everywhere
Superior long-term stability	Superior short -term stability
Subject to RFI	Immune to RFI
Requires ground and space infrastructure	Self-contained

Some of INS and GNSS technologies characteristics

GNSS/INS integration strategies

The three most common strategies for integration of GNSS/INS are (ordered by increasing complexity and performance): loose coupling, tight coupling and ultra-tight integration. The fundamental difference between them is the type of data shared by the GNSS receiver and the INS sensors:

- In the loosely-coupled technique, position and velocity estimated by the GNSS receiver are merged with those from the INS navigation solution.
- In the tightly-coupled method, GNSS raw measurements are processed through a unique Kalman filter alongside measurements coming from the inertial sensors to estimate the PVT.
- Ultra-tight or deep integration involves the baseband signal processing of GNSS receivers (i.e. output of the correlator measurements and input of numerically-controlled oscillator (NCO) commands), in a vector tracking manner. The integration filter sends control commands to the NCO, thus enabling superior GNSS tracking performance.

Historically, 'lower grade' (> 10 nautical miles of error per hour) IMUs have been used in loosely coupled solutions, while the more sophisticated tight or ultra-tight solutions integrate 'navigation grade' (1 nautical mile of error per hour) IMUs and high-grade professional GNSS receivers.

Sensors are improving

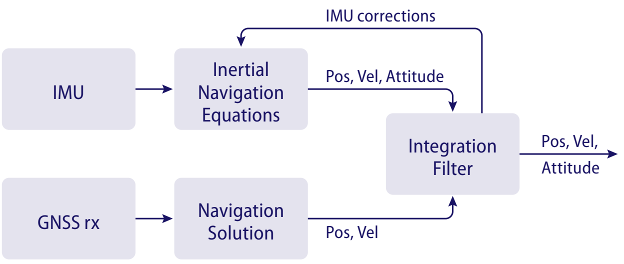
Small, robust and low-cost inertial sensors (e.g., Micro Electrical Mechanical Sensors (MEMS) have been available on the market for several years and are delivering ever increasing performance. As an example, the best MEMS-based accelerometers are currently navigation grade. In parallel, progress in optical technology and photonics enable miniaturisation and manufacturing of fibre optic gyroscopes (FOGs) at low C-SWaP (cost, size, weight and power).

On the GNSS side, high-end mass market chipsets currently provide access to processing techniques such as PPP or RTK. When combined with inertial sensors in advanced fusion software, they enable superior positioning and orientation performance, making this combination the basis for a variety of new services requiring high reliability, continuity and accuracy.

Key factors for GNSS/INS integration

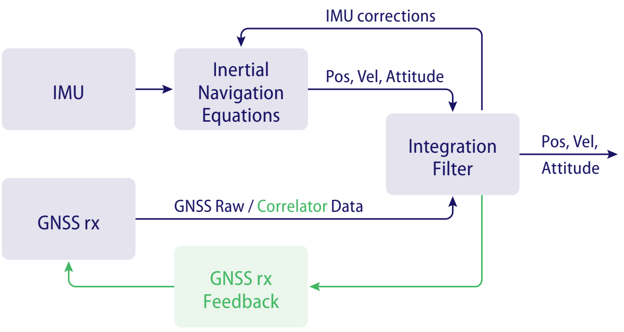
Despite the obvious complementarity, integrating these two technologies requires attention in a few areas including: i) good a priori definition of the carrier dynamics, to select suitable IMUs and provide the filter with a good motion model, ii) efficient quality control of the GNSS measurements to reject potential outliers, iii) near-perfect synchronisation of the INS and GNSS measurements. For high-accuracy solutions, the selection of a GNSS antenna with good phase centre stability to allow level arm effects compensation is also required. When observing these conditions, GNSS/INS integration is the ideal 'core PNT' solution that provides improved robustness and accuracy in all environments.

Loose INS/GNSS integration



Loose INS/GNSS integration offers significant benefits. The INS bridges short-term GNSS reception gaps, provides attitude and low noise, high rate position updates between GNSS fixes. GNSS provides long term stability and calibration of the INS errors.

Tight and ultra-tight INS/GNSS integration



Tight and ultra-tight architectures start providing benefits with as few as one GNSS satellite in use. Access to GNSS raw measurements enables, inter alia, very accurate velocity calibration for the INS. In the ultra-tight case (at the baseband processing level) the integration filter can interact with the GNSS tracking loops to provide superior anti-jamming performance.

EUROPEAN GNSS DOWNSTREAM INDUSTRY AT THE FOREFRONT OF INNOVATION

European downstream GNSS industry is at the cutting edge of innovation in some GNSS solutions thanks to substantial investment in R&D.

Some members of the industry have benefitted from European R&D funding mechanisms including Horizon 2020 and Fundamental Elements.

This page features four innovative technologies developed by Galileo Services members.

There are still many unexplored opportunities for GNSS applications and services in Europe.

Galileo Services

The leading industry organisation focusing on downstream in the European GNSS programmes:

- Non-profit organisation founded in 2002
- Network representing more than 180 companies
- Member companies active across the whole value chain and in all domains of applications
- Stimulates downstream technology (terminals, applications and services) to maximise the potential of the GNSS applications market

More information at: http://www.galileo-services.org

Page provided by Galileo Services

SATGUARD by FUGRO

SATGUARD™ is a Navigation Message Authentication system covering all GNSS constellations. SATGUARD servers validate the messages using information collected from our proprietary global receiver network, and provide signatures allowing users to authenticate the navigation messages they receive. A similar protection of the correction data for the G4 PPP service is also included. SATGUARD provides a simple means of detecting faked GNSS signals.

More information at: fugro.com

GSS9000 by Spirent

The GSS9000 simulator features up to 320 channels and 10 outputs in one chassis. With sub-0.3 millimetres RMS pseudorange accuracy, a stable 1 KHz simulation iteration rate, and maintaining full specification performance at channel capacity and maximum dynamics, the GSS9000 is a test tool for critical and demanding applications.

More information at: spirent.com

© Spirent

GIDAS by OHB Digital

GNSS Interference Detection & Analysis System is used as a standalone monitoring station for interference detection and classification. Features include real-time GNSS signal monitoring, multi-signal band monitoring (GPS: L1, L2, L5; Galileo: E1, E5; GLONASS: G1, G2; BeiDou: B1, B2; SBAS), GNSS interference detection, classification of GNSS interference signals, and analysis and comparison of interference events in post-processing.

More information at: ohb-digital.at

MOSAIC™-X5 by Septentrio

© Septentrio

Compact, Low-power, multi-band & multi-constellation GNSS receiver module, supporting all Galileo bands and ready for E6. Designed for mass market applications. Advanced anti-jamming and anti-spoofing technology. Uncompromising RTK performance which provides highly robust centimetre-level positioning with extremely low latency and very high update rate at 100 Hz.

More information at: septentrio.com

GSA TOOLS THAT DRIVE INNOVATION OF GNSS APPLICATIONS AND TECHNOLOGY

GSA GNSS downstream R&D programmes

To foster the adoption of Galileo and EGNOS-powered services across all market segments, the GSA supports two complementary R&D funding mechanisms:

Fundamental Elements (FE) focuses on supporting development of innovative chipsets, receivers, and other associated technologies that integrate Galileo and EGNOS into competitive devices for dedicated user communities/target markets.

Horizon 2020 (H2020) encourages the adoption of Galileo and EGNOS via content and application development. It also supports the integration of E-GNSS services into devices, along with eventual commercialisation.

The Fundamental Elements of European GNSS

Fundamental Elements

With a budget of €100 million over 2015 – 2020, Fundamental Elements aims to develop market-ready GNSS chipsets, receivers, and antennas. The markets targeted by these end-products include all segments, to varying degrees: Aviation, Consumer Solutions, Agriculture, Surveying, Rail, Road, Maritime, Timing and Synchronisation and government-approved users (PRS). By end of June 2020, three projects were successfully concluded, with 19 ongoing and many upcoming. There have been 73 entities involved from 13 different European countries.

The funding of Fundamental Elements supported activities including grants of up to 70% of the total budget as well as tenders/procurement.

In line with the current developments, a next FE Work Programme (WP) is being defined. It will continue to be driven and prioritised by application user needs and target commercial products with the implementation of current Galileo unique value-added services.

More information can be found here: gsa.europa.eu/r-d/gnss-r-d-programmes/fundamental-elements

HORIZON 2020

Horizon 2020

Horizon 2020 is the current EU Research and Innovation programme, offering nearly €80 billion in funding over 2014 – 2020. European GNSS applications are part of the Space Theme, having synergies with topics on societal challenges. All five H2020 calls on E-GNSS market uptake have now been launched, with a total budget of €139.3 million.

More information about the projects can be found here: gsa.europa.eu/gnss-h2020-projects

There are currently 70 H2020 projects granted within H2020 E-GNSS market uptake calls (excluding the 5th call projects to be signed by the end of 2020). These projects have supported 434 beneficiaries from 29 countries. SMEs have receive important support, accounting for 34% of the sum of the EU grant budget.

Overall, H2020 projects help to maximise the uptake of Galileo and EGNOS and to realise the potential of the European GNSS industry, and contribute to growth, competitiveness and jobs in the sector, while enabling public benefits.

More information can be found here: gsa.europa.eu/r-d/h2020/introduction

Horizon Europe

The upcoming Framework Programme will bring new funding opportunities for E-GNSS downstream applications. During consultations on E-GNSS Research and Innovation funding priorities, stakeholders agreed that after 2020 the priorities are the following:

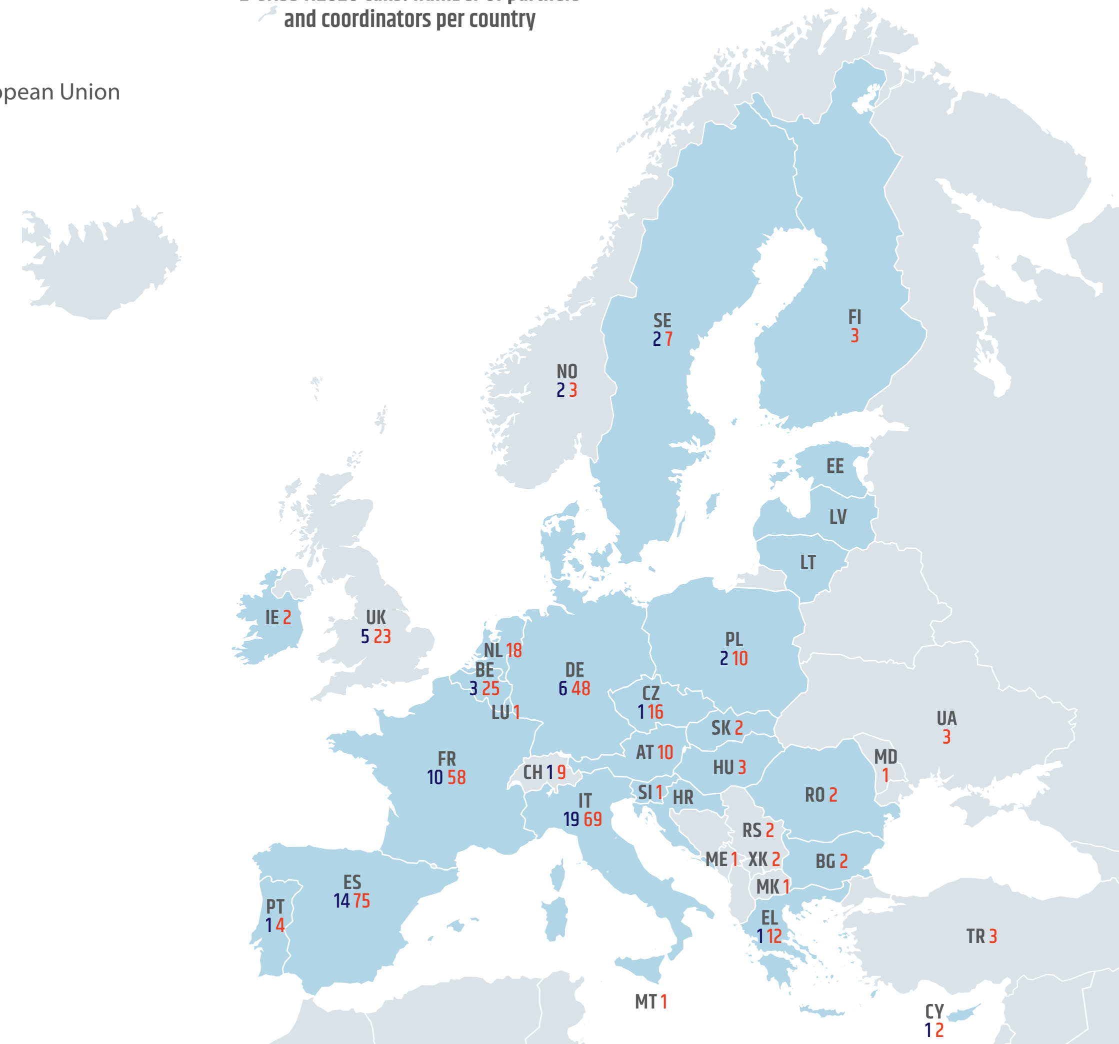
- Continue the development of fundamental elements and close-to-market E-GNSS applications, linked to EU strategic challenges.
- Foster market uptake in regulated market segments that has longer-term implementation cycles.
- Position Galileo as a leader in segments where its unique features/differentiators make a difference.
- Support the Public Sector as a customer of Galileo.
- Foster competitiveness of the EU downstream industry and SMEs/start-ups and leverage regional competences.

More information can be found here: gsa.europa.eu/sites/default/files/uploads/european_gnss_downstream_research_innovation_priorities_and_consultation_results.pdf

STATISTICS ON FOUR H2020 E-GNSS CALLS HIGHLIGHT STRONG EUROPE-WIDE INTEREST

E-GNSS H2020 calls: number of partners and coordinators per country

- Member States of the European Union
- 1 Number of coordinators
- 1 Number of partners



Non-EU countries (outside of depicted area)	Number of Partners
Australia	1
Brazil	5
Canada	3
China	3
Egypt	1
India	4
Israel	1 and 2 coordinators
Japan	3
Malaysia	1
Morocco	1
Palestine	1
Samoa	2
Senegal	3
Thailand	2
Togo	1
United States	1
VietNam	2
Taiwan	3
Korea	2
Dominican Republic	1

Four E-GNSS H2020 calls in a nutshell

EU27:

- Entities from 23 member states involved
- 60 coordinators and 374 partners involved in total

Outside EU27:

- Entities from 29 countries involved
- 10 coordinators and 87 partners and involved in total

European Space Week 2020: Make space in your calendar

Mark your calendar for European Space Week 2020, and don't miss out on the leading European space programmes conference, connecting business, policy-makers, international experts and space application user communities. The event takes place online from 7 to 11 December 2020.

Member States of the European Union (EU): AT Austria, **BE** Belgium, **BG** Bulgaria, **CY** Cyprus, **CZ** Czech Republic, **DK** Denmark, **DE** Germany, **EE** Estonia, **EL** Greece, **ES** Spain, **FI** Finland, **FR** France, **HR** Croatia, **HU** Hungary, **IE** Ireland, **IT** Italy, **LT** Lithuania, **LU** Luxembourg, **LV** Latvia, **MT** Malta, **NL** Netherlands, **PL** Poland, **PT** Portugal, **RO** Romania, **SE** Sweden, **SI** Slovenia, **SK** Slovakia, **UK** United Kingdom (until 31 January 2020).
Non-EU countries: CH Switzerland, **ME** Montenegro, **MK** Macedonia, **MD** Moldova, **NO** Norway, **RS** Serbia, **TR** Turkey, **UA** Ukraine, **UK** United Kingdom (as of 1 February 2020), **XK** Kosovo.

HIGH-VOLUME DEVICES

FAST AQUISITION AT LOW POWER DESIRED IN THE HIGH-VOLUME MARKET

Characterisation of high-volume devices

High volume devices are those devices intended for widespread use and produced in large volumes. Within this report, they refer to the GNSS-technology solutions related to the following applications:

- **Consumer solutions:** smartphones/tablets, wearables and portable devices;
- **Internet of Things** (IoT): physical devices connected to the internet;
- **Automotive solutions:** tracking and navigation (as self-driving vehicles are safety-critical, they have been included in the next macrosegment chapter);
- **Drones:** devices with chipset technology similar to other high-volume devices, and with less stringent performance requirements on parameters such as accuracy than safety-and liability-critical devices. Typically, high-volume devices relate to the 'Open' category of the EASA drone categorisation, which includes drones that fly below 120m and within visual line of sight (VLOS);
- **Robotics:** tracking and navigation with a focus on those that require outdoor positioning;
- **Augmented Reality;** and
- **Sports solutions,** including **leisure maritime and aviation solutions.**

In many areas, there is a trend towards using high-volume devices for professional applications. A key example of this is innovative devices developed for leisure maritime and aviation are being used in professional and even military applications due to their advanced features. These technologies include smartwatches and portable navigation devices developed for consumer use, which are now sophisticated enough to be used as backup navigation devices in professional and military settings. Smartphone applications are also beginning to rival the capabilities of dedicated professional navigation and chart plotting/route planning technologies in the aviation and maritime fields.

Key performance parameters for mass market

The definition of the key performance parameters for the high-volume market have not changed since the previous report. However, the importance of the parameters vary among different high-volume applications.

All high-volume applications are interested in high availability and low Time-To-First-Fix (TTFF), however, a low TTFF is of prime importance for drones, robotics and automotive solutions. Indoor penetration is also a key concern for most high-volume applications, while it presents a medium priority for drones, as most consumer drones are used outdoors. Power consumption is important across all high-volume solutions but is a key priority for IoT applications.

Accuracy is of moderate importance in most applications, while augmented reality, robotics and automotive applications place higher importance on this parameter. Latency has a lesser importance for most high-volume applications, except for robotics and augmented reality applications, which require low latency to provide a truly immersive experience.

High-volume devices key performance parameters

Key Performance Parameter (KPP)*	High-volume Devices
Accuracy	Medium priority
Availability	High priority
Continuity	Medium priority
Indoor penetration	High priority
Integrity	Low priority
Latency**	Low priority
Power consumption	High priority
Robustness	Medium priority
Time-To-First-Fix (TTFF)	High priority

High priority
Medium priority
Low priority

* The Key Performance Parameters are defined in Annex 3

** Latency is of high priority for robotics and augmented reality applications, but is of lesser priority to other high-volume applications

HIGH-VOLUME DEVICES RESPOND TO DIVERSE PERFORMANCE REQUIREMENTS

High-volume device applications vary in their level of maturity. Applications such as location-based services and automotive navigation have well-defined use cases and established market players. Applications including consumer drones and mHealth are beginning to reach maturity after years of technology and market development. Other applications including augmented reality, robotics and smart clothing are emerging markets with rapidly developing use cases and technological needs. The figure below (left) shows a summary of the level of maturity of main applications.

In addition to having diverse levels of maturity, high-volume applications vary in their performance requirements. Applications differ in the level of accuracy they require from GNSS chipsets, as well as in the frequency of position updates.

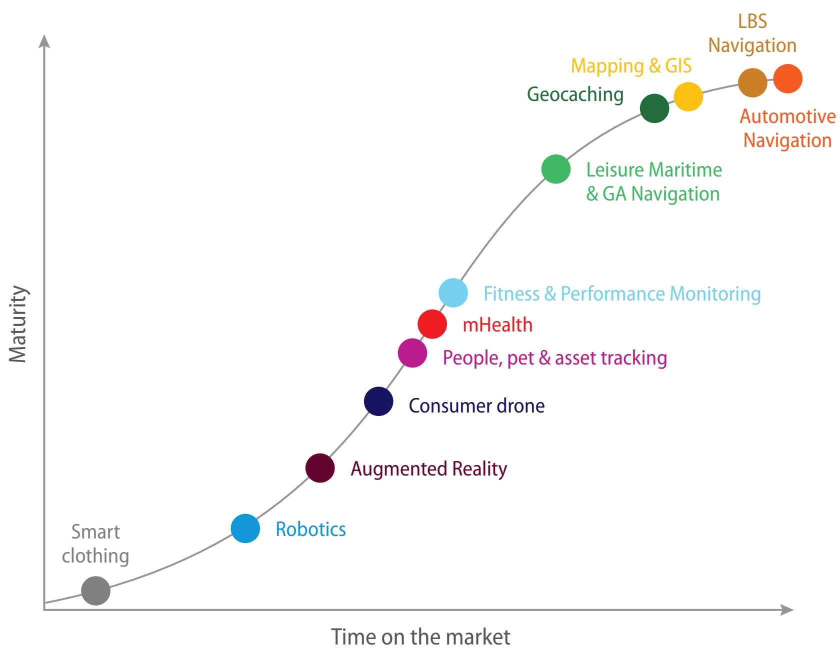
The figure on the bottom right charts the performance requirements with relation to accuracy and update rate for common high-volume GNSS applications.

High-volume device applications with high performance requirements regarding both accuracy and update rate include AR applications, robotics, and mapping and GIS.

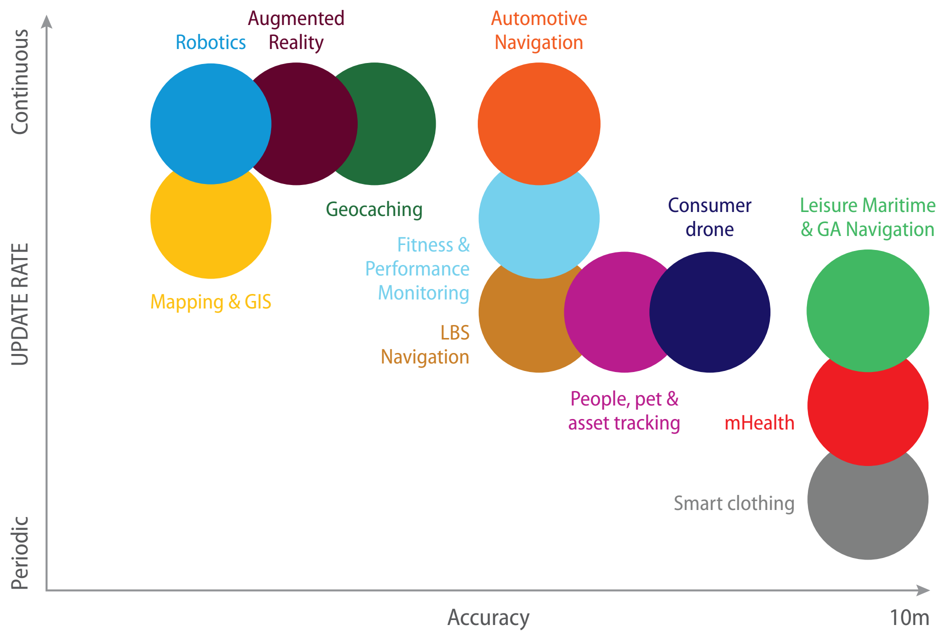
The middle of the chart shows applications that require moderate accuracy levels and update rates, including LBS, automotive navigation, fitness tracking, geocaching and drones.

Applications that require periodic updates and accuracy in the range of 5-10 metres include mHealth and leisure maritime and General Aviation navigation.

Level of maturity of high-volume device applications



Relative performance requirements of high-volume device applications



DUAL FREQUENCY IS THE NEW DIFFERENTIATOR WHILE MULTI-CONSTELLATION EXPANDS IN BUDGET DEVICES

Multi-constellation is now standard for high-volume chipsets. In the high-end and mid-range smartphone chipset market, dual frequency is becoming the norm. All large players have released dual-frequency chipsets, and the first dual-frequency chipsets targeting the budget device market are now becoming available.

Maximum use of constellations

The inclusion of all possible constellations is a key trend, as providers now move to include all available constellations in their chips in order to achieve enhanced availability and accuracy. This is becoming the case even in mid-range and budget phones, showing the democratisation of multi-constellation technology and the blurring of the divide between premium and low-cost devices. Some chipsets announced in 2020 saw NavIC added to the mix of constellations in chipsets for the first time.

A majority of silicon chipsets are manufactured in fabrication plants in the Asia, including in particular, the 'low end' of the market. As a result there is a boom in the low-end market from companies based in the region. These companies adopt BeiDou and GLONASS by default.

Dual frequency becoming widely available

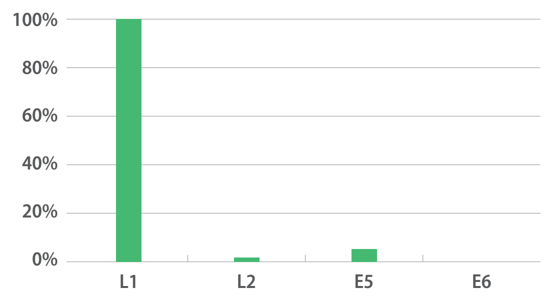
Dual frequency has not only become a strategic choice for high-end devices but is also entering the mid-range smartphone market.

2017 saw the introduction of the first premium high-volume chipsets incorporating L5/E5a signals. Smartphones incorporating these chipsets were first launched in June 2018, with encouraging high-accuracy positioning results. Until June 2020, more than 50 smartphone models with dual-frequency capabilities have been launched.* Although there are many different dual frequency smartphone models, they share a smaller number of chipsets and as a result the dual frequency support in the charts may be underestimated.

The market is expected to adopt dual frequency as a mainstream option for mid-range and, subsequently, budget phones. However, single frequency still dominates the chipsets currently on offer in terms of models. Dual-frequency receivers offer improved accuracy and robustness, and potential access to high-accuracy techniques. Previously, such techniques were only common in professional products. However, challenges still persist with the use of high-accuracy techniques within most high-volume devices, due to issues including the use of low-quality antennas, the use of duty cycling and the lack of phase tracking.

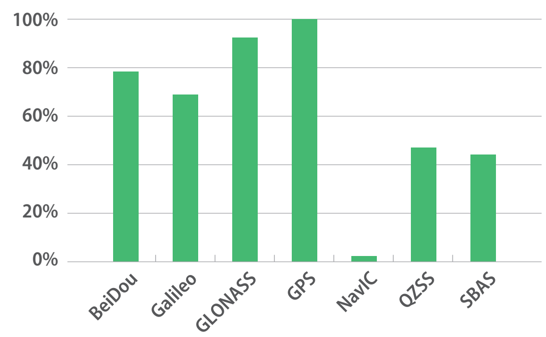
* Visit usegalileo.eu for a comprehensive list of dual-frequency smartphone models

Frequency capability of GNSS receivers[1]



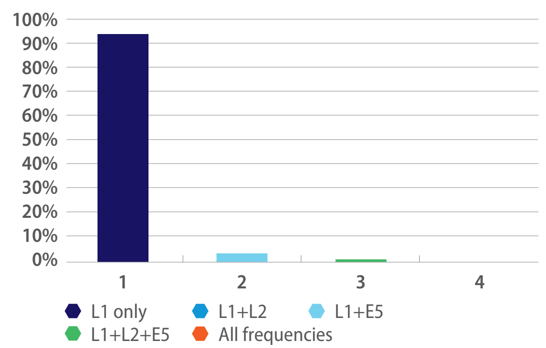
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



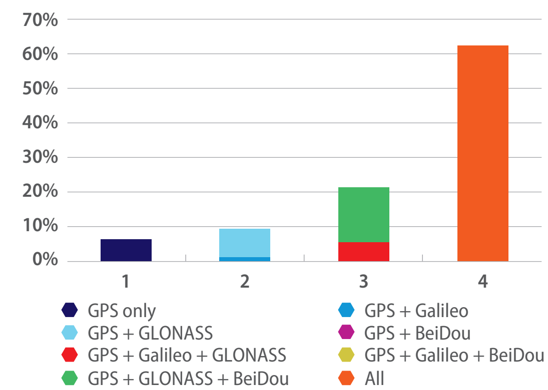
[2] shows the percentage of receivers capable of tracking each constellation

Supported frequencies by GNSS receivers[3]



[3] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 frequencies

Supported constellations by GNSS receivers[4]



[4] shows the percentage of receivers capable of tracking 1, 2, 3 or all 4 global constellations

Disclaimer: The above charts reflect manufacturer's publicly available claims regarding their product's capabilities and judgement on the domains to which they are applicable. Use in actual applications may vary due to issues such as certification, implementation in the end user product, and software/firmware configuration.

DESPITE VERTICAL INTEGRATION OF THE SMARTPHONE SUPPLY CHAIN, FLAGSHIP MANUFACTURERS RETAIN THEIR MARKET POSITION

Key players retain dominance, new players enter smartphone market

Qualcomm, Broadcom and Mediatek dominate chipset sales to the high-end and mid-range smartphone market. New players from Asia, such as Allystar and Unisoc, provide chipsets to the Asian and African smartphone market, and are gaining market share. Another tendency is the move towards in-house production of chipsets by smartphone providers, including Samsung, Huawei and Apple. This helps controlling costs, and guards against over-dependence on external manufacturers. However, it often comes with a trade-off in terms of functionality. Indeed, for high-end devices, smartphone providers continue to purchase chipsets from flagship manufacturers.

DJI leads the drone market, while u-blox provide platform-integrated chipsets. In automotive, u-blox, Qualcomm and Broadcom are active in the navigation segment, while u-blox and STMicroelectronics lead the smart mobility segment. In wearables and IoT, Broadcom, Mediatek and u-blox hold significant market shares.

A major step forward in dual frequency GNSS with BCM4776

With flagship smartphones already benefiting from L1/E1 + L5/E5 dual frequency GNSS, Broadcom has focused on raising the bar yet again.

Complex technology success stories are always a team effort. No single entity can achieve the same results as a synchronised team. That is an important factor behind this year's GNSS innovation by Broadcom, tapping into the completion of the BeiDou3 constellation by including its signals in the L5/E5 band. The brand new BCM4776 chip adds support for the B2a and B1C signals of Beidou3 and optimises support for the L1/E1 + L5/E5 signals of GPS and Galileo.

The entire Galileo programme is fully committed to the dual frequency L1/E1 + L5/E5 and pilot signals technologies, and has driven it to maturity during the last decade. With the combination of Galileo+BeiDou3, results are now spectacular – 30 additional L5 and pilot signals – and available in BCM4776, which provides higher location accuracy, higher sensitivity and lower power.

This L1+L5 maturity level achieved in BCM4776, coupled with the now ubiquitous L5 signals, has enabled very exciting new features. A good example is the much improved L5-based urban pedestrian performance. Another example is the use of advanced corrections to the L5 signals to achieve lane-level accuracy for motorway driving. This Broadcom technology, called HDGPS, is expected to power next year's flagship smartphones.

Synchronising different teams towards the common goal of higher GNSS performance is definitely worth the effort, and the industry collaboration around BCM4776 has proven that. Broadcom has raised the performance bar again!

Testimonial provided by the company

Increasing adoption of dual frequency and wideband E5 only chipsets entering the market

Broadcom became the first chipset manufacturer to offer dual-frequency chips in 2017. In 2020, Qualcomm released three dual-frequency Snapdragon chipsets and Lenovo and Allystar released the first smartphone chip capable of tracking BeiDou's B2a signal. In September 2020, oneNav announced its entry into the market with the first ever single frequency, wideband E5 GNSS receiver. Because of its simplicity, the single frequency design is well suited to highly size constrained devices such as smartphones and wearables. This is an important milestone, leveraging the high quality wideband E5 signals, and a potential turning point for high-volume devices, achieving high performance with innovative designs.

Acquisitions help strengthen the position of dominant players

In 2019, Apple acquired Intel's GNSS division as part of a wider acquisition of Intel's smartphone modem business. Apple and Qualcomm have reportedly reached a multi-year agreement for the supply of parts, so Apple may follow the path of Samsung and continue to source a share of chips externally. u-blox has diversified its IoT offering by acquiring Rigado's Bluetooth business. Rigado's portfolio of Bluetooth products includes low-energy modules providing Edge-as-a-Service for IoT. The acquisition is intended to open new markets for u-blox in the smart home, wearables and fitness segments.

Leading components manufacturers

APPLE (INTEL)	North America	*intel.com*
BROADCOM	North America	*broadcom.com*
HUAWEI (HISILICON)	Asia-Pacific	*hisilicon.com*
MEDIATEK	Asia-Pacific	*mediatek.com*
QUALCOMM	North America	*qualcomm.com*
SAMSUNG	Asia-Pacific	*samsung.com*
STMICROELECTRONICS	Europe	*st.com*
U-BLOX	Europe	*u-blox.ch*
UNISOC	Asia-Pacific	*unisoc.com*

Note: This list does not include system and terminal integrators, and therefore some key industry players may not appear in the list. Manufacturers appear in alphabetical order.

HIGH VOLUME CHIPSETS VARY BETWEEN LBS, IOT, DRONES AND AUTOMOTIVE

Typical state-of-the-art receiver specifications for the high-volume devices macrosegment

Features		LBS chip	IoT chip	Drones module	Automotive* module
Dimensions		4 x 4 x 0,5 mm	4 x 4 x 0,5 mm	24 x 24 x 4 mm	12 x 12 x 2 mm
Weight		0.1 g	0.1 g	8 g	1 g
Operating temperature range		-40 to +85°C	-40 to +85°C	-40 to +85°C	-40 to +105°C
Power supply		1.4 - 3.6 V	1.4 - 4.3 V	1.8 - 5.5 V	1.65 - 3.6 V
Current consumption	Hibernate	10 µA	10 µA	15 µA	15 µA
	Acquisition	19 mA	17 mA	37 mA	24 mA
	Tracking	3-8 mA	0,5-8 mA	22 mA	22 mA
Number of channels		72	72	72-184	72-184
Number of frequencies		1-2**	1	1-2**	1-2**
Time-To-First-Fix	Cold start	<30 s	<30 s	<30 s	<32 s
	Hot start	<1.5 s	<1.5 s	<2 s	<2 s
	Aided starts	<3 s	<3 s	<2 s	<4 s
Sensitivity	Tracking	-167 dBm	-160 dBm	-167 dBm	-167 dBm
	Acquisition	-160 dBm	-160 dBm	-160 dBm	-160 dBm
	Cold start	-148 dBm	-148 dBm	-148 dBm	-148 dBm
	Hot start	-156 dBm	-157 dBm	-157 dBm	-157 dBm
Max navigation update rate		5-10 Hz	2-10 Hz	10-25 Hz	5-30 Hz
Velocity accuracy		0.05 m/s	0.05 m/s	0.05 m/s	0.05 m/s
Horizontal position accuracy	Autonomous	2.5 m	2 m	1.5 m	2.5 m
	SBAS	2 m	N/A	1 m	1.5 m
Accuracy of time pulse signal	RMS	30 ns	N/A	30 ns	30 ns
	99%	60 ns	N/A	60 ns	60 ns
Frequency of time pulse signal		0.25 to 10Hz	N/A	0.25 to 10Hz	0.25 to 10Hz
Operational limits	Dynamics	<4 g	N/A	<4 g	<4 g
	Altitude	50,000 m	N/A	50,000 m	50,000 m
	Velocity	500 m/s	N/A	515 m/s	515 m/s

Disclaimer: The above specifications represent a typical chip/SoC package or module based on manufacturer's published literature for their latest products. Consequently discrepancies may exist between the installed receiver's characteristics and those stated above.

** Excludes chipsets for safety-critical/autonomous applications.*
*** Premium chipsets now incorporate dual frequency.*

LBS and IoT manufacturers often adopt System-on-Chip (SoC) solutions including wafer-level packaged GNSS receivers, while the drone and automotive manufacturers prefer to adopt module solutions. LBS devices remain primarily L1 and support multiple constellations. The multi-constellation reception feature maximises the number of satellites in view and offers more opportunities to apply smart power management strategies to reduce power consumption. The adoption of dual GNSS frequency bands is now spreading not only to premium, but also to mid-range smartphones. Duty-cycling remains the favoured approach to reduce power consumption, and A-GNSS remains integral to delivering the required fast TTFF.

For the IoT, significant hardware advancements have helped to reduce the overall energy consumption and some GNSS chipsets are now able to consume less than 1,5 mW (0,5mA for a 3V power supply) in continuous tracking mode. Latest developments in Low Power Wide-Area Networks (LPWAN) offer further opportunities to reduce the GNSS energy consumption by providing assisted data, autonomous ephemeris prediction as well as cloud-based snapshot positioning and outsourced position calculation (see page 19 for more on power strategies).

Drone receivers are required to provide high accuracy and are typically supplied to drone manufacturers as a module (or an OEM board) incorporating MEMS accelerometers/gyros and other functions. Automotive and drone applications now share similar requirements for high accuracy GNSS receivers and rapid convergence time. Automotive and drone missions time are not constrained by the current GNSS receivers' power consumptions. As a result, GNSS receivers have started to adopt multi-frequency (L1, L2 and E5), as well as concurrent constellation reception mode and offer to track SBAS satellites as well as local base stations to achieve sub-metre accuracy.

DUAL FREQUENCY IMPROVEMENT PROVEN IN TESTING

Over recent years, smartphones have evolved from using GPS-only to multi-constellation GNSS. Since 2018, more and more smartphones (e.g. Xiaomi Mi 9, Huawei Mate 20 Pro, Samsung Galaxy Note10) are able to receive E5a (L5) as an additional frequency allowing smartphones to estimate and correct for the ionospheric delay and reduce the multipath impact.

In 2019, the GSA launched an extensive testing campaign in order to assess the GNSS performance of dual-frequency smartphones. The test campaign was conducted in different modes (static and dynamic) and environments (e.g. open sky, urban, motorway) in order to understand and measure the benefits of dual-frequency smartphones.

The testing campaign was based on both live and simulated signals. In total six smartphones (three of them able to receive dual frequency) were tested. The smartphones were selected to ensure a variety in terms of chipsets manufacturers and date of release.

Three setups were considered for the live tests: static, pedestrian and vehicle. Tests with the simulated signals were performed at the Joint Research Centre of the European Commission. A radio constellation simulator was used to generate the signals to the anechoic chamber. Among others, the following metrics were monitored:

- **Cumulative Distribution Function (CDF) of the horizontal position error** – presented in Figure 1.
- **Number of tracked satellites per constellation and frequency over time** – presented in Figure 2.

Figure 1 presents the results for the best performing single- and dual-frequency smartphones that were used in the testing campaign. It shows the cumulative distribution of the horizontal error for Xiaomi Mi 9 (dual-frequency chipset) in red and for Samsung Galaxy S10+ (single-frequency chipset) in blue. It can be observed that Xiaomi Mi 9 outperforms Samsung Galaxy S10+ in all the scenarios (suburban, urban, highway). Figure 2 presents the number of tracked Galileo and GPS satellites by Huawei Mate 20 Pro on E5a and L5 respectively. For the whole test Huawei Mate 20 Pro tracked more Galileo satellites on E5a than GPS satellites on L5.

CDF of the horizontal position error Samsung Galaxy S10+ (SF) vs Xiaomi Mi 9 (DF) Dynamic tests

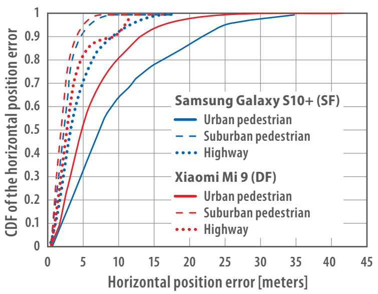


Figure 1

Number of tracked satellites, E5a/L5 signals, Open Sky 4h assisted

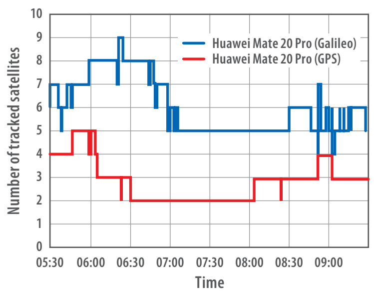


Figure 2

Summary of achievable accuracy with single- and dual-frequency smartphones

Positioning technique	Positioning mode	Single-/dual-frequency GNSS chipset	Position accuracy in meters	Additional information
Standalone	Real time	single-frequency	5 – 25	Smartphone: Samsung Galaxy S10+ Test case: the highest accuracy corresponds to open sky static test and the lowest to urban pedestrian case
Standalone	Real time	dual-frequency	2 – 15	Smartphone: Xiaomi Mi 9 Test case: the highest accuracy corresponds to open sky static test and the lowest to urban pedestrian case
PPP	Real time	dual-frequency	2	Smartphone: Xiaomi Mi 8 Test case: suburban pedestrian
PPP	Post-processing	dual-frequency	0.2	Smartphone: Xiaomi Mi 8 Test case: open sky static
RTK	Real time	dual-frequency	1	Smartphone: Xiaomi Mi 8 Test case: suburban
RTK	Post-processing	dual-frequency	0.01	Smartphone: Xiaomi Mi 8 Test case: open sky Additional details: choke ring platform was used to reject ground multipath, smartphone was placed on the rotating platform, base station was established next to the test setup

The table above presents a summary of achievable accuracy with single- and dual-frequency smartphone GNSS chipsets (or for short single- or dual-frequency smartphones) when using different positioning techniques or modes. The presented results are based on the actual testing campaign and on a literature review. The benefits of using dual-frequency smartphones are clear in urban environments in which smartphones face strong multipath. In open sky environment, the benefits of using dual-frequency smartphones are lower especially during nominal ionospheric activity. Position accuracy can be improved by using techniques like Real Time Kinematic (RTK) and Precise Point Positioning (PPP). High accuracy can be achieved especially in the post-processing when using final orbit and clock products.

The final configuration uses an external antenna whilst other configurations use the integrated antenna in the smartphone.

ANDROID GNSS RAW MEASUREMENTS UPDATES

Android GNSS Raw Measurements Task Force Workshop

GSA organised its annual GNSS Raw Measurements Task Force Workshop online on 27-28 May 2020 with more than 200 participants from 32 countries. The objective was to share the Task Force members' experience and progress around the use of raw measurements within Android devices.

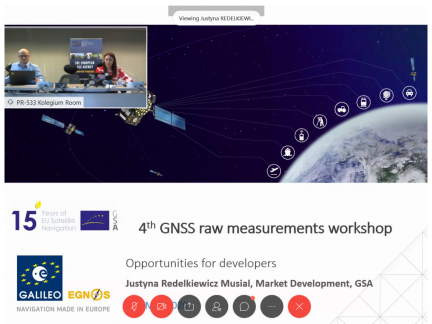
GNSS raw measurements allow developers to use the carrier and code measurements, as well as the decoded navigation messages from mass-market devices. This enables the creation of advanced GNSS positioning algorithms, more ambitious smartphone-based services, and access to data contained in the navigation message, such as OS-NMA (see the box on the right for more information on benefits of GNSS raw measurements).

During the workshop Google reviewed the achievements on the Raw Measurements project including more than 17,000 downloads of the analysis tools and the generation of hundreds of research papers. Google also announced updates in tools for logging and analysing GNSS measurements, such as logging in RINEX format, logging of other sensor data (in the GNSS Logger app), new PVT filters, and 'select satellite for position' (in GNSS Analysis software). Additional features (e.g. antenna phase centre offset), to be available with the release of Android 11 in the third quarter of 2020, were also highlighted.

Discussions and more than 20 presentations at the workshop from the Task Force members confirmed that GNSS raw measurements are increasingly used in educational and scientific projects around the world, leading to increased knowledge and interest in GNSS technology and better implementation of GNSS within smartphones. In addition, there is already a growing body of evidence that sub-metre positioning is feasible in real time with current smartphones when using RTK and other techniques. So, it is just a question of when, rather than if, it will be used widely.

The Android GNSS Raw Measurements Task Force

The Android GNSS Raw Measurements Task Force is dedicated to promoting a better and wider use of GNSS raw measurements. Since its launch in 2017, the Task Force has expanded from a handful of experts to a community of over 150 agencies, universities, research institutes and companies. Membership is open to anybody interested in GNSS raw measurements. To join the Task Force contact: *market@gsa.europa.eu*



Further information about the Task Force and workshops' presentations can be found at: *gsa.europa.eu/gnss-applications/gnss-raw-measurements*

Benefits of GNSS Raw Measurements

Scientific use and research and development

- Observations provided in a coarse form can be used for testing hardware and software solutions and for new post processing algorithms e.g. for modelling ionosphere or troposphere.

Increased Accuracy

- Access to raw measurements allow developers to employ advanced positioning techniques (RTK, PPP) and create a solution that is currently only available in professional receivers. It results in a technological push to develop new applications.

Integrity/Robustness

- Access to raw measurements will offer new ways to detect RF interferences and to locate the interference source by combining the measurements from multiple devices (crowdsourcing), or verify the data source (OS-NMA).
- SBAS corrections can be incorporated without the need for additional equipment.

Testing, performance monitoring and education

- Raw measurements can be used for monitoring performance (data, accuracy, receiver clock), testing and to compare solutions from individual constellations, eliminate specific satellites or test for worst scenario performance.
- Understanding GNSS, signal processing or displaying orbits, signal strength and other aspects is a valuable tool for educational purposes.

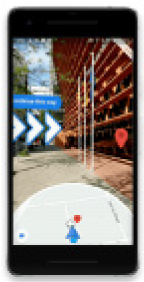
Google solving GNSS wrong-side-of-street problems in cities

Google

Google has provided raw GNSS measurements from Android phones since 2016. Now Google is using these raw measurements to generate corrections to the errors caused by reflected GNSS signals in cities. These reflected signals produce locations on the wrong-side-of-street (WSS). Almost everyone has experienced this when using GNSS in cities, particularly when walking.

Thanks to Google's extensive database of maps and 3D building models, a solution to the WSS problem is now at hand. In 2020 Google released 'Project Bluesky'. In its first release Bluesky reduced the WSS occurrence by 50%. In its second release, Bluesky further reduces WSS occurrences by 75%.

Google has been working closely with all major GNSS chip manufacturers to implement and test an API that provides corrections to the errors produced by the GNSS reflections. These corrections enable a much more accurate location in cities. GNSS signals in the L5/E5 band are key to the solution, and Galileo plays the largest role of any GNSS system, with all its satellites providing high accuracy signals in the E5 band.



Users can experience these 'Bluesky' benefits in any Android phone that runs version 8 or later. If the phone has Galileo E5 the accuracy improvements will be greater.

Google has also released *LiveView*, a new paradigm for walking navigation in cities. *LiveView* uses images and Bluesky for unprecedented accuracy in cities.

Testimonial provided by the company

HIGH ACCURACY CORRECTION SERVICES ENTER HIGH-VOLUME DEVICES

In recent years there has been a grand push towards delivering high-accuracy services to high-volume devices. Numerous players traditionally targeting high-accuracy services have entered this competitive arena, as well as players from other fields, including telecommunications network operators. In addition to this, most public GNSS providers have released, or have plans to release, high-accuracy services. It is clear that the demand for high accuracy from high-volume devices appears as an attractive business opportunity for a large and varied group of organisations.

Public high-accuracy services come to the high-volume market

Most GNSS and SBAS providers have released high-accuracy services in recent years or have plans to release such a service. Japan's Quasi-Zenith Satellite System (QZSS) launched its Centimetre Level Augmentation Service (CLAS) in 2018. Galileo has plans to release the High Accuracy Service (HAS), which will be based on the free transmission of Precise Point Positioning (PPP) corrections through the Galileo E6 signal and will allow users to obtain a positioning error around twenty centimetres. These high-accuracy services by public providers are free to use and represent attractive options for the price-conscious high-volume device market.

New commercial approaches to high-accuracy services

Developments in the area of autonomous and connected vehicles have been a key driver of the launch of commercial high-accuracy services targeting high-volume devices. Various approaches have been taken to address this large perceived market opportunity from a technology standpoint.

Companies like Sapcorda and Swift Navigation use QZSS CLAS to deliver accuracy of less than 10 centimetres and cite their methods to achieve low convergence time at less than 30 seconds as a key competitive advantage.

These companies also compete on coverage, generally focussing on coverage of the continental US and Europe, and on availability, which is often achieved using low-bandwidth data transfer over cellular networks.

Other companies combine dual-frequency receiver capabilities with cloud-based correction services to achieve high levels of accuracy. At the Consumer Electronics Roadshow 2020 (CES), HERE Technologies announced a cloud-based service called HD GNSS, providing sub-metre level accuracy worldwide to high-volume devices. The service relies on dual-frequency receivers to deliver PPP-RTK services.

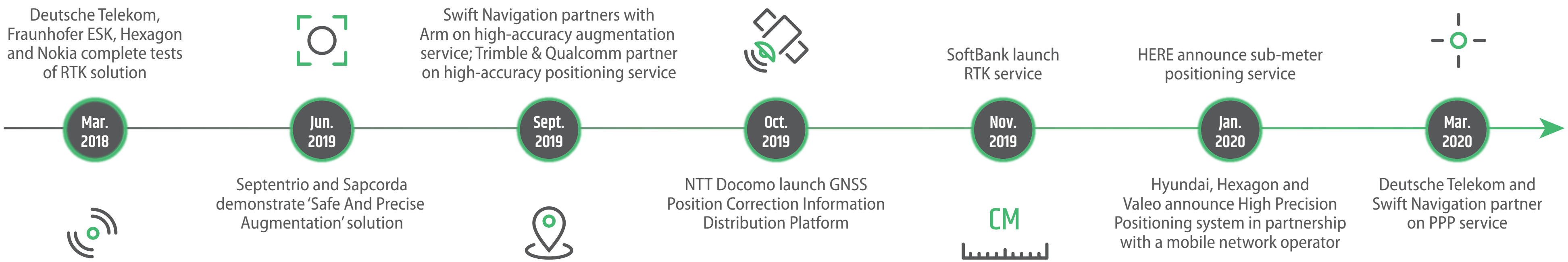
Telecom operators enter the high-accuracy market

Japanese telecommunications network operators such as Softbank and NTT DoCoMo have created RTK services that draw their 5G base stations, which are used as GNSS reference stations. SoftBank has installed RTK reference stations in 3,300 of its 5G base stations. As 5G infrastructure is expensive, the opportunity to generate additional revenues from this infrastructure is attractive for network operators.

Other operators, such as Deutsche Telekom are adopting PPP-RTK based corrections, in which mobile infrastructure is used to broadcast correction data collected from GNSS data providers, who maintain their own network of GNSS reference stations. In this setup, the value-added by telecoms operators is the ability to transfer corrections data quickly, leading to real-time positioning updates for devices using the service. This is achieved through advanced mobile connectivity methods, including edge computing.

With so many new services on the market, and highly performant free services offered by public GNSS providers, it is likely that winners and losers of this race will emerge, as some players achieve a strong position on the market while others are left behind.

Timeline for launch of high-accuracy augmentation services



ADVANCEMENTS IN RECEIVER TECHNOLOGY ENABLE GNSS TO MEET IOT LOW-POWER REQUIREMENTS

Recent advancements in low power consumption open up new markets that GNSS could not previously serve. These developments, discussed on page 19, are particularly relevant for IoT devices. Many IoT applications stand to benefit from the precise localisation offered by GNSS, such as asset, people and animal tracking, eBike applications, and wearables. However, many of the devices used for these applications use infrastructure-based localisation methods (such as WiFi and LPWAN positioning) which come at virtually no cost since the technology is already built-in. In this context, the benefit-cost ratio of adding GNSS may look unattractive, especially if considering the full energy consumption of older GNSS chipsets.

Advancements in receiver technology and in computational techniques make the trade-off between power consumption and positioning accuracy increasingly swing in favour of GNSS for outdoor IoT applications. Assisted GNSS (A-GNSS) uses the communication network of the IoT device to download clock, ephemeris and other support data at faster transmission speeds than those of satellite navigation messages. A-GNSS allows the GNSS receiver to achieve a position fix much faster, at lower energy consumption. When communication networks with very low downlink capacity are used (such as some proprietary LPWAN networks), autonomous ephemeris prediction techniques can be used instead of A-GNSS. However, as ephemeris data are subject to frequent change due to satellite orbit perturbation and other environmental effects, ephemeris prediction techniques come with a trade-off in accuracy.

GNSS chipset manufacturers have developed intelligent power management strategies to reduce overall power consumption by using the minimum resources required during tracking whenever possible (CPU is kept asleep as much as possible, Low Noise Amplifier (LNA) and clocks do not have to be ON all the time). With these strategies, the full-power scheme is solely activated to maintain positioning performance in case of weak signals or a low number of visible satellites. Therefore, the increasing use of multi-constellation contributes to reducing the average power consumption. Improvements in the development of specialised low-power hardware such as Analogic Digital (AD) converters, low noise amplifiers and electronic circuit phase-locked loops (PLL) for the RF circuit also contribute to reducing the overall power consumption.

The figure illustrates the typical battery life of three different applications (smartphones, sport watches and drones) when the GNSS is ON or OFF. Activating GNSS has a negligible impact on the drone mission duration. The smartphone battery life is less affected by GNSS power consumption than previously owing to the use of intelligent power management strategies as well as the control of the GNSS receiver duty cycle. However, GNSS receivers are much more important in sport watch mission durations. The implementation of intelligent power management strategies as well as the combined use of snapshot GNSS technologies (see page 40) and Low Power Wide Area Networks (LPWAN) contribute to the development of 'ultra-low' power GNSS receivers, which are able to consume significantly less than in full power mode (bellow 10 milliwatts in tracking mode).

Low-power implementation and high accuracy further increases the appeal of GNSS

SONY

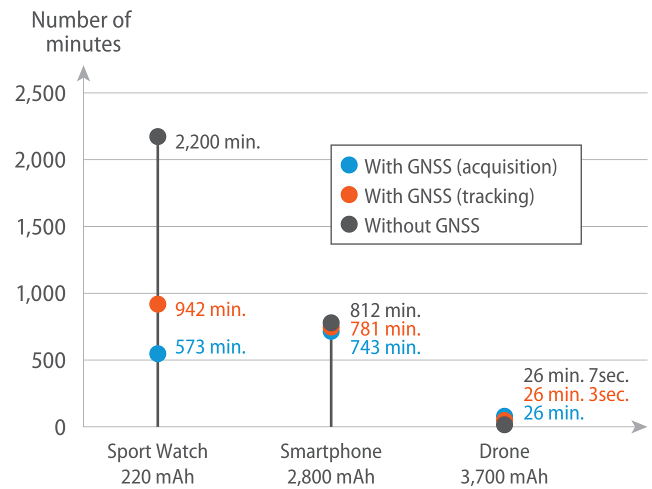
Sports wearable users demand accuracy and near-continuous tracking when running, cycling and swimming. For mass deployment and user acceptance, driver behaviour monitoring devices deployed by insurance companies require update rates of 1Hz and simple installation for the customer i.e. no connection to vehicle power supply and battery life of 1+ years. Tracking goods shipments at the level of individual assets requires small, robust, very low-cost trackers with long battery life.

Duty-cycle techniques alone are insufficient to meet the use cases defined above. To meet this challenge and widen the use of GNSS, Sony launched a range of GNSS L1 receiver integrated circuits several years ago. These circuits use innovative silicon design techniques such as the Silicon-on-Insulator process and very-low voltage RF circuits, the latest product, CXD5605, consumes just 6mW when continuously tracking.

Each use-case requires specific algorithms to optimize performance. For example; sports wearables benefit from an algorithm to compensate for arm swinging during running and vehicle tracking applications benefit from untethered dead-reckoning algorithms when the GNSS signal is temporarily lost e.g. in tunnels. Users continue to demand even higher levels of accuracy, so Sony has created a new L1 + L5 device, the CXD5610GF, which uses the same design techniques as CXD5605GF, maintains the very low-power consumption, and has significantly improved accuracy when compared with L1-only receivers.

Testimonial provided by the company

Some use-cases of battery life



Source: FDC internal study

Disclaimer: Battery life depends on the chipset power consumption. The durations above have been assessed based on typical receiver specifications. Consequently discrepancies may exist between the actual battery life and the one stated above.

SNAPSHOT POSITIONING, AN INNOVATIVE METHOD TO REDUCE CHIPSET POWER CONSUMPTION

Snapshot positioning

As discussed on the previous page, snapshot positioning is a technique that records a digital copy of a received GNSS signal for a very short time: usually 2ms-100ms compared to 1-10s for a traditional receiver. The recorded digital copy is used to determine the signal frequency and code phase before calculating the pseudorange. The receiver's coarse position and time are required as input to eliminate ambiguities on the pseudorange. The collected pseudoranges are then used in combination with ephemeris data provided as input to compute the receiver's accurate position and time. This technique saves on battery consumption by removing the need for continuous tracking of GNSS signals, and by simplifying hardware requirements.

Snapshot positioning can be used in tandem with other techniques such as remote processing to further reduce power consumption. With remote processing signal processing, pseudorange, and position estimation can be offloaded to a cloud-based server. When using snapshot positioning combined with remote processing, there is a price to pay in power consumption for the communication channel, making it critical to choose an economical network technology.

As the key limitation is the overall lifetime of the IoT device's battery, it is important that techniques to reduce GNSS power consumption do not cause a larger increase in the power consumption of the communications module. With the goal to optimise the sum of power consumption from the GNSS and communications module, the method chosen to do so will depend on the available communications infrastructure (e.g. cellular or proprietary LPWAN). The GSA whitepaper on *Power-efficient positioning for the Internet of Things* discusses these trade-offs and the potential power reductions achievable in more detail.

Snapshot receiver configurability

For applications which do not require real-time positioning, signal data can be captured and stored for processing. This allows the GNSS receiver to turn on for a very short amount of time, and enables energy-consuming computation tasks to be carried out when battery is less critical, such as during recharge. For real-time applications, signal data be processed immediately.

Snapshot receivers can be configured such that signal processing and position estimation occurs on the device, but ephemeris data is retrieved from the cloud server at convenient times, e.g. during battery recharge. The Apollo and Galileo of Things projects are two examples of R&D initiatives exploring these new features.

Accurate GNSS POsitioning for Low power and Low-cost Objects (APOLLO)

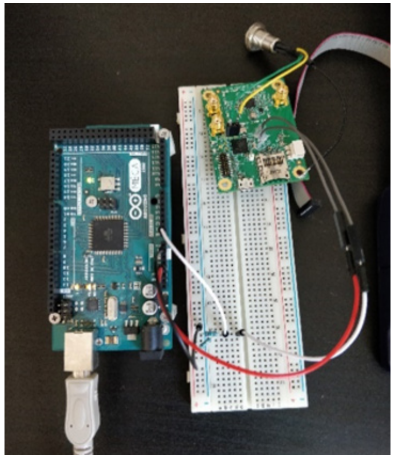
European Global Navigation Satellite Systems Agency

Fundamental Elements

APOLLO aims at providing a Galileo-based location solution for IoT, reducing device complexity and reducing energy consumption by a factor between 10 and 300.

APOLLO is delivering to the market:

- A 100% software GNSS receiver getting rid of chip and the related constraints (consumption, size etc.);
- An optimized location algorithm with unequalled computation speed between about 100ms and 3sec to acquire and treat the data necessary on the receiver side to compute the object's PVT in the Cloud depending on the partitioning method used;
- A distributed architecture with part of the algorithm executed on the IoT processor and part of it on a remote server in the Cloud.



Galileo Of Things (GOT)

European Global Navigation Satellite Systems Agency

Fundamental Elements

GOT aims to increase Galileo relevance in the high-volume market by delivering a Galileo Semiconductor Intellectual Property (IP) core that combines with narrowband-IoT IP.

Such combination will enable:

- Lower chipset cost and, furthermore, the lowest complete complexity;
- Lower power consumption on both GNSS and connectivity;
- Minimum electronic area size;
- Best trade-off between accuracy & power owing to the Galileo constellation.

The developed IP will consist of sub-components that are ready-to-integrate and match the requirements of targeted customers of the consortium.

More information at: ubiscale.com/gnss-ip-core-galileo-of-things/

ACHIEVING SEAMLESS POSITIONING WITH HYBRIDISATION

Indoor positioning and challenges for hybridisation with GNSS

Technology providers often use a mixture of methods to achieve indoor positioning, which represents a challenge in terms of hybridisation with GNSS signals in order to provide seamless positioning. Recent advancements in the area of WiFi positioning and Ultra Wide Band (UWB) technology and their continued adoption in high-volume devices such as smartphones, make these technologies attractive candidates for hybridisation with GNSS.

WiFi RTT, UWB and Ultra-sonic to achieve high accuracy indoors

Important advancements have been made in WiFi positioning with Round Trip Time (RTT) technology, a protocol which allows devices to measure the distance between the device and nearby WiFi routers. WiFi RTT uses time-of-flight to measure the time it takes for a signal to be sent from a WiFi router to a device such as a smartphone, as well as the time it takes for a message acknowledging receipt of the signal to be sent from the device back to the WiFi router. Implementing this technology with a single WiFi router results in accurate distance measurement between the router and the receiving device. With three or more WiFi routers, trilateration can be utilised to give an accurate position. This improves WiFi positioning from 5-15 metre accuracy to the level of 1 metre accuracy.

UWB technology is a relatively new technology in the sphere of consumer devices. UWB offers accuracy between 10 and 30 centimetres in an indoor environment. It requires that the user or object to be tracked carries a UWB tag, which transmits UWB signals to static 'anchor' UWB tags. It requires a direct line-of-sight between the moving and anchor tags.

Ultra-sonic solutions can be used to achieve accuracy of 1-2 centimetres. As ultra-sonic signals do not travel through walls they can be used to position a user within a room. Rebounding signals and requirements for the wearing of mobile tags by users, however, causes potential issues for adoption. Ultra-sonic technologies largely target professional applications in places such as hospitals and may not be as relevant for high-volume devices.

Greater adoption of WiFi RTT and UWB in smartphones

In 2018 Google moved towards greater reliance on WiFi positioning by adding support for RTT to Android Pie and later Android versions. This suggests that, in future, WiFi will continue to be a leading technology for indoor positioning.

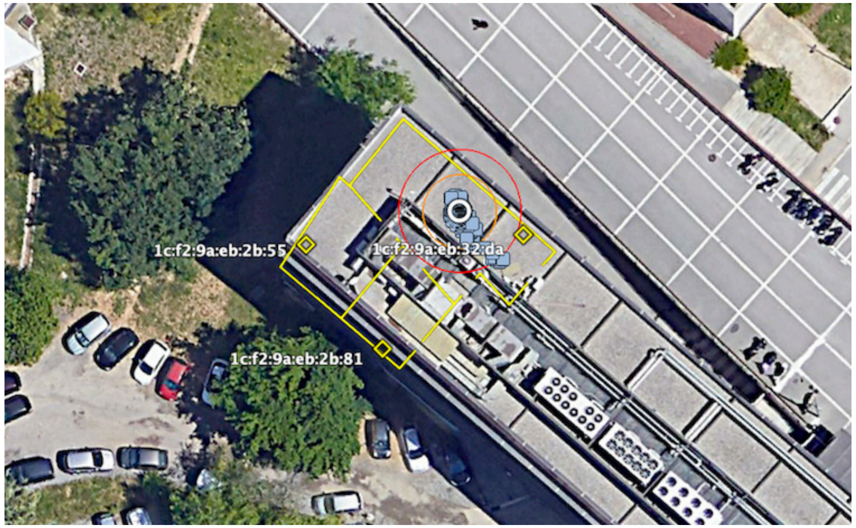
In August 2019, Samsung, Xiaomi, Oppo and other industry players created the FiRa consortium in order to foster the development of an interoperable UWB ecosystem. The creation of this consortium demonstrates the desire of some smartphone industry players for widespread adoption of UWB. In September 2019 Apple released iPhone 11, which includes a UWB chip. As the required UWB anchor technology for indoor locations was not yet widespread, the applications of this iPhone technology were limited at the time of release. The inclusion of UWB technology in the iPhone, however, represents a step towards greater adoption of UWB, as well as opening up the potential for greater hybridisation of UWB and GNSS for seamless positioning.

GRETEL: ubiquitous accurate and affordable urban navigation

ROKUBUN

WiFi can be now utilised for precise location leveraging the ranging measurements of the Round Trip Time protocol of IEEE 802.11mc. The advent of precise satellite positioning in smartphones and the initial penetration of hardware compliant with the 802.11mc protocol, makes it possible to foresee an accurate, scalable, and ubiquitous mainstream navigation technology serving high-volume applications in the next five-year period.

Rokubun is prototyping a new navigation technology, GRETEL, oriented to smart cities. GRETEL hybridises GNSS raw and WiFi ranging measurements in order to provide accurate ubiquitous navigation able to seamlessly transit from outdoors to indoors and vice versa, and enhance navigation in harsh urban environments. One of the major challenges for the uptake of such a technology is the precise geolocation of WiFi RTT access points, in order to subsequently use them as pseudo-satellites providing ranging measurements. Rokubun's GRETEL addresses this challenge and, in addition to the hybrid positioning engine in the user device, promising results which point to metre-level navigation accuracy are already being delivered.



Demonstration of full indoor WiFi RTT-based navigation using WiFi RTT compliant routers (yellow diamonds). Blue points represent position estimation, and orange and red circles are 3m and 5m deviations relative to the reference position (white circle).

Testimonial provided by the company

QUANTUM TECHNOLOGIES: SOLVING COMPLEX NAVIGATION PROBLEMS

Quantum technologies and potential for navigation

Quantum computing can be used to address complex problems that are difficult for traditional computers to solve. Traditional computers rely on binary processors called bits, which can exist in a state of 0 or of 1. This forces computer programmes to work through problem sets one by one. For complex problems this can take significant amounts of processing time. By contrast, quantum computers work with qubits which can exist in multiple states at a time. This enables quantum computers to work through all possible problem sets at the same time, arriving at the solution much faster.

While GNSS is a well-established technology domain, certain navigation and GNSS applications stand to benefit from quantum technologies due to their complex nature and the ability to improve outcomes using quantum methods.

Quantum navigation algorithms

Quantum algorithms are designed to solve problems using quantum methods. As quantum hardware is still in its infancy, most of these algorithms are currently being simulated on traditional computers in order to demonstrate their potential impact.

Automotive navigation in densely populated areas is a perfect example of a problem involving complex computation. The complexity occurs when numerous drivers, each with a different starting location and end location, request an optimal route.

Current navigation systems first steer drivers towards the most direct routes, and then divert subsequent drivers when these routes becomes congested. These systems currently employ traditional computing techniques are not advanced enough to compute all possible routes and distribute drivers optimally among them.

Volkswagen and Ford have completed tests of quantum algorithms for navigation, showing a significant reduction in traffic delays. Ford, in partnership with Microsoft, demonstrated a scenario with 5,000 cars requesting routes simultaneously. Using quantum algorithms they were able to reduce average commuting times by 8%.

Quantum computing can be used to solve another difficult navigation problem; when a traveller has multiple destinations planned, what is the shortest overall route? This is known as the 'travelling salesman problem' and has been studied in the field of optimisation for several decades.

Quantum computing, with its ability to break the travelling salesman problem into subsets and consider each combination simultaneously, allows this problem to be solved efficiently. Quantum computing opens future possibilities in fields such as logistics and transport.

Quantum Sensing

An aspect of quantum mechanics known as entanglement can be used to overcome current hardware constraints, which limit the speed and accuracy of sensors. Entangled particles are tied together so anything that happens to one particle affects the particles with which it is entangled. Researchers at the University of Arizona have demonstrated[1] that a network of several sensors can be entangled with one another, meaning they all receive the information from probes and correlate it with one another simultaneously. For applications that use a network of sensors, such as those used to detect RF waves, this can significantly improve sensing performance. In the case of GNSS, the greater speed and improved accuracy of time delay or angle of arrival measurements for GNSS signals via the use of quantum sensing could enable better indoor localisation and spoofing detection.

Quantum Encryption

As society enters the Quantum Era, current cryptographic methods will be challenged by the greater computing power of quantum computers. In order to deal with this technological leap and stay ahead of potential attacks, encryption techniques might need to adapt by employing quantum technologies and methods as well. This could be the case for encrypted GNSS signals, such as the Galileo PRS, OS-NMA and CAS signals. While the threat of quantum attacks on encrypted signals is some years from realisation, owing to the immature nature of current quantum technology, research into protection against this threat must begin now to keep pace with potential attacks. A consortium including the University of Darmstadt and the Fraunhofer Institute began work on the QuantumRISC project in 2019, which seeks to protect against quantum attacks on embedded systems with a focus on automotive engineering applications. With extensive levels of funding currently available we can expect to see more new studies emerging in this area as quantum techniques develop.

1 Physical Review Letters, April 2020

NEW FRONTIERS IN MASS-MARKET APPLICATIONS: ROBOTICS AND AUGMENTED REALITY

GNSS and sensor fusion supporting robotics navigation

The 2018 GSA User Consultation Platform (mass market section) showed a clear focus on continuous positioning updates and high levels of accuracy for the robotics sector. While GNSS can meet these requirements to a certain extent, as use cases of service robots move increasingly towards outdoor urban environments, buildings can frequently obstruct GNSS signals and other moving objects can obstruct planned navigation routes. Therefore sensor fusion techniques are needed to address challenges and prevent unwanted collisions.

Sensor fusion to meet all navigation requirements

Inertial technologies are commonly used to augment GNSS signals to ensure robots adhere to the planned navigation path. Accelerometers and gyroscopes are used to calculate direction and speed, and are merged with GNSS signals to provide accurate and continuously updated positioning information.

Visual navigation systems incorporating Simultaneous Localisation and Mapping (SLAM) technology and object recognition are key to avoiding objects in busy environments. An example of this is KiwiBot, a service robot designed for last-mile food delivery. The robot combines visual-based navigation and GNSS technologies to ensure it stays on-route, without colliding with unexpected obstacles.

Addressing accuracy and durability

In order to address GNSS accuracy requirements, Septentrio released a triple-frequency module called mosaic which uses RTK technology to guarantee maximum accuracy and availability (see details on page 27). It is not common for modules focussed on the high-volume markets to support RTK, however, this shift in design choice is a response to the clear requirement for high accuracy within robotics applications.

Durability is also a key concern for service and other robots. Swift Navigation have partnered with Carnegie Robotics to design a product called Duro Inertial, which combines GNSS and inertial technologies to deliver a continuous positioning solution. The Duro range of modules is ruggedised, demonstrating the need of robotics hardware to be reliable under harsh or unexpected environments.

Augmented Reality

While Augmented Reality (AR) technology experienced a surge in popularity in the mid-2010s, it is poised for another growth spurt due to the enhanced AR capabilities enabled by 5G.

5G has the potential to reduce latency problems that have so far plagued AR applications, allowing AR to become more mainstream and ubiquitous. In order to realise the potential for providing fully immersive experiences, however, it is also key for many AR applications to benefit from highly accurate location capabilities.

As concluded by the 2018 GSA User Consultation Platform, AR applications have high requirements for accuracy and continuous positioning. The popularity of smartphone-based software development kits (SDKs) like ARKit and ARCore among augmented reality developers mean that several recent developments in the smartphone market, such as dual-frequency smartphone chips, should facilitate the higher accuracy needed for location-aware augmented reality applications.

Additionally, AR is likely to be a key driver for the adoption of PPP and RTK services in consumer applications, and technology development efforts stand to benefit from projects such as Flamingo and telecommunications-GNSS service provider partnerships that will bring sub-metre accuracy to the high-volume market in the near future (see page 38).

HIGH GNSS PERFORMANCE IS REQUIRED IN LEISURE, SPORTS AND FITNESS SOLUTIONS

Blurring of professional and high-volume applications

As high-volume GNSS technologies continue to improve, the lines between professional and high-volume devices are increasingly blurred. This is most clearly seen in the aviation segment, where leisure aviation devices are now being used as backup navigation solutions by military users.

An example of this is Garmin's line of aviation watches, which now include required features such as moving maps and the ability to track satellite-based augmentation systems (SBAS) to act as an emergency backup navigation system for professional pilots. According to statements by Garmin, their Charlie D2 watches are being used by United States Air Force pilots of the Lockheed U-2 aircraft. In 2018, Garmin added Galileo capabilities to their new aviation watch series, the D2 Delta.

Other advanced devices such as portables navigation devices (PNDs) now include synthetic vision and user-friendly touchscreens that are not yet seen in commercial airliners. Newer PNDs and head up displays (HUDs) also enable certified leisure pilots to fly instrument flight rule (IFR) procedures allowing for safer landings in all weather conditions, further aligning the professional and high-volume segments.

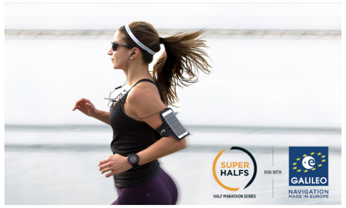
In addition to the improvement in device capabilities, mobile applications such as SkyDemon allow pilots to plan routes in a matter of seconds, significantly changing a once lengthy manual task.

These innovations on a range of lightweight and often interconnected devices are placing general aviation on the cutting edge of avionics and allow pilots to fly more safely than ever.

Sports and fitness applications also display the democratisation of solutions traditionally foreseen for professional players. Monitoring and tracing equipment for runners, bikers and skiers have become an indispensable part of every workout. More determined runners compare route and speed measurements from multiple applications and devices.

Specialised watches and wearables are expected to deliver more accurate tracking results compared with smartphones, and added value is clearly expected from the purchase of additional hardware. Dual frequency multi-constellation features have therefore entered the smartwatches market and users are even able to select the constellation mix directly on the device.

SuperHalfs Marathon



Galileo partnered with 'Run with Galileo' by SuperHalfs – a series of five half marathons across Europe – to bring a precise fitness tracking and navigation experience to thousands of runners. Originally taking place in Lisbon, Prague, Copenhagen, Cardiff, and Seville, due to Covid-19 the Superhalfs turned into Virtual Superhalfs, going beyond borders and reaching a global audience with thousand of runners competing across the world.

More information at: superhalfs.com

For PNT needs in outdoor environments, GNSS is a very important technology, appreciated in a wide range of sports. Usage of GNSS signal technology does, however, feature some well-known limitations, such as indoor reception issues and increased power consumption. For seamless and accurate positioning, Geonav is testing a solution that hybridises GNSS and UWB to ensure continuity during rugby games in partially closed stadiums (see box below for details).

Another innovation is to offset the power needs of GNSS by using the available energy sources; namely the body heat of the person wearing the watch, and solar energy (see the Power Watch Series 2 below).

Seamless Positioning in a Stadium Environment (GEONAV)

HORIZON 2020

GEONAV is an example of a professional sports application, designed to deliver highly accurate positioning and performance data for the French national rugby union team.

GEONAV combines GNSS technology with Ultra Wide Band (UWB) to achieve high levels of accuracy. It is an example of a seamless positioning application (discussed in detail on page 41).

GNSS tracking device are worn between the shoulder blades of players. They have been miniaturised down to roughly smartphone-size and incorporate accelerometers based on MEMS as well as GNSS receivers.

Further information can be found at: *gsa.europa.eu/galileo-dual-frequency-5g-iot-devices-and-services-drones-assets-management-and-elite-sport*

From Low-Power to No-Power Consumption (Power Watch Series 2)

© Matrix Industries

GNSS-enabled watch. Announced at CES 2019, it is charged based on the body heat of the wearer, as well as solar-powered technology.

Retailing at $499 it is in the price range of premium consumer smartwatches. However, it provides less functionality than its counterparts such as Garmin. It can be expected that the high price point will decrease as the highly innovative no-charge technology becomes more mainstream.

More information at: powerwatch.com/products/powerwatch-2

E-GNSS SUPPORTS UBIQUITOUS POSITIONING IN CITIES AND CHALLENGING ENVIRONMENTS

PNT performance delivered by European GNSS, including both Galileo and EGNOS, provide a relevant contribution to high-volume device users. Galileo satellites are effective in boosting ubiquitous positioning in challenging environments, such as cities, where many users in high-volume markets often operate. Modern chips embedded in smartphones and other high-volume devices are indeed capable of receiving signals from many GNSS constellations, including Galileo. This has a positive impact in all the key performance parameters, including accuracy, availability and TTFF. Nevertheless, Galileo provides specific features capable of 'making a difference'. Among these, a relevant contribution is **better resistance to multipath interference**. This is especially true in the case of dual-frequency smartphones owing to the unique shape of the E5 signal provided by Galileo satellites, which further makes it easier to distinguish direct signals from those reflected by buildings. The popularity of dual-frequency chips is increasing (more than 50 smartphone models currently offer this feature).

Additionally, Galileo is the only GNSS that offers **navigation message authentication** (OS-NMA), a feature expected to be of high interest for application and service providers as it could enable innovative commercially-sensitive applications.

Enhanced positioning accuracy creates opportunities for many new applications in areas such as augmented reality, vehicle navigation, and mapping. It will also support the potential use of smartphones for professional activities and as an alternative to existing dedicated devices.

EGNOS, with applications traditionally designed for aviation, adds value in drone solutions and general aviation applications using high-volume devices, reducing the ionospheric error and thus improving accuracy and robustness.

E-GNSS Contribution to Key Performance Parameters

Key Performance Parameter (KPP)*	EGNOS contribution	Galileo contribution
Accuracy	⬢⬢⬡ (medium)	⬢⬢⬡ (medium)
Availability		⬢⬢⬡ (medium)
Continuity		⬢⬢⬡ (medium)
Indoor penetration		⬢⬡⬡ (low)
Robustness	⬢⬢⬡ (medium)	⬢⬢⬡ (medium)
Time To First Fix (TTFF)		⬢⬢⬡ (medium)

* The Key Performance Parameters are defined in Annex 3

⬢⬢⬢ Major contribution, capable of enabling new GNSS applications

⬢⬢⬡ Medium contribution, enhancing the user experience

⬢⬡⬡ Low contribution, performances improved but no major difference at user level

FLAMINGO Project & Raw Galileo Hackathon

FLAMINGO was a Horizon 2020 project that developed a positioning service along with an API, which allowed users with either Smartphones or IoT devices to obtain their position accurate to metre-level or better in a seamless manner, with a simple interface to be subsequently integrated into apps and Location Based Services.

FLAMINGO was an innovation rather than an invention, in that processes and protocols in common use within the GNSS industry were re-used and adapted for use for mass-market devices. The user interface was a Google geolocation style API, and behind the scenes FLAMINGO used the RTCM format and NTRIP protocol to deliver various GNSS data and services, and PPP and RTK approaches within the positioning engine. The FLAMINGO service made use of Galileo to its utmost extent given the current limitations of high-volume devices, as the service provided corrections to both E1/L1 and E5/L5.

The *Raw Galileo 24-hour hackathon* took place in March 2020, organised by the University of Nottingham and the GSA as part of the FLAMINGO project. Participants were challenged to develop solutions on two topics; develop new or enhanced solutions using Galileo and the high-accuracy positioning and navigation services provided by FLAMINGO, and demonstrate non-navigation uses of GNSS raw measurements. For the first topic, **VastMapping** won with an app that used Galileo and FLAMINGO accuracy to provide real-time computer vision for asset-mapping and management. For the second topic, first prize went to **ClaimR app**, a verified location signing service.

Further information can be found at: flamingognss.com

SAFETY-*AND LIABILITY-** CRITICAL DEVICES

* Safety-critical devices are defined as those for which misperformance of GNSS can lead to potential direct or indirect harm to humans (death or injury), destruction of the carrier vehicle, damage to external properties or to the environment.

** Liability-critical devices are defined as those for which undetected GNSS misperformance can result in significant legal or economic consequences.

INTEGRITY REIGNS SUPREME EVEN AS APPLICATIONS DEMAND INCREASED ACCURACY

Characterisation of the transport safety- and liability-critical devices macrosegment

This macrosegment covers receiver technology for safety- and liability-critical applications in **aviation**, **maritime**, **rail** and **road** transportation. These sectors utilise mature technology built in accordance with rigorous standards and often subject to certification, driving a need for similar levels of performance. These segments, however, also exhibit different technical constraints based upon their operational environments, which can impose unique requirements.

Critical to improvements across all domains, that often support increased automation, is the ability to track vehicles in a traffic management system. Increasingly this is delivered through an integrated communications, tracking and navigation supersystem, with the vehicle at the centre reporting its own location. This places additional requirements on time synchronisation. Examples include ADS-B in aviation, AIS in maritime, V2X systems in road and ERTMS in rail. This continues to require an **always-available** positioning system, with **integrity**, **continuity**, and **robustness** of paramount importance, and demand increasing **accuracy** to support new applications. GNSS receiver technology, as part of a tightly coupled suite of sensors, is at the heart of this supersystem – including provision of timing to support transport infrastructure, which is discussed in detail in the chapter on timing solutions.

Personal Navigation Devices (PNDs) including phone applications and smart watches are increasingly being used within the leisure aviation and maritime markets for moving maps or chart plotters, bringing benefits of better integrated communication, tracking and navigation. These devices, however, rely on the availability of high-volume (mass market) technology, and as such are discussed more extensively within the 'high-volume devices' chapter of this report. The lower price point and refresh rate of technical improvements enabled by the use of such high-volume chips, bring additional benefits when integrated within both aviation and maritime consumer products to support safety-critical applications. As robustness, reliability and accuracy of these devices has improved, this has led to development of applications with lower deployment costs, allowing safety benefits and supporting Search and Rescue (SAR).

Key performance parameters*

Assurance is the keyword for safety-critical systems. Before entering into service/operation, any application must be approved, based on suitable assurances that the overall system (which includes processes, people and procedures as well as equipment) will be safe. This invariably pivots on the confidence in the navigation or positioning performance, which must be established before commercial operations are deployed.

The key performance parameters for this macrosegment are:

1. **Integrity:** In safety-critical applications, specifically alerting if accuracy limits are exceeded is essential to avoid catastrophic events (including loss of life). In liability-critical applications, integrity is paramount to avoid incorrect application of charges or fines.
2. **Continuity:** It is important to ensure that the application is successfully delivered. For example in aviation, a loss of navigation during a procedure will result in abandoning the procedure. Liability-critical applications need continuity in order to ensure records are valid and there are no adverse economic impacts.
3. **Robustness:** Whilst jamming (particularly self-jamming in the case of liability-critical applications) can disable applications, and spoofing (including self-spoofing) could introduce serious safety or liability risks, unintentional RF interference (e.g. man-made or solar-induced) can cause serious disruption of services.
4. **Accuracy:** An increasing number of applications are required to operate within denser populated environments, requiring high performance accuracy, so this parameter is becoming a higher priority for the macrosegment.
5. **Availability:** Applications need to be able to function at any point in time and across large geographical areas, with lower dependence on infrastructure and weather conditions.

Safety-and Liability-Critical Devices Key Performance Parameters

Key Performance Parameter (KPP)*	Safety - and Liability- Critical Devices
Accuracy	High priority
Availability	High priority
Continuity	High priority
Indoor penetration	Low priority
Integrity	High priority
Latency	High priority
Power consumption**	Medium priority
Robustness	High priority
Time-To-First-Fix (TTFF)	High priority

High priority Medium priority Low priority

* The Key Performance Parameters are defined in Annex 3

** Power consumption could be critical for aerial drones

THE MATURE TRANSPORT SECTORS ARE STEADILY MOVING TO INCREASED RELIANCE ON GNSS FOR FUTURE APPLICATIONS

LEADING COMPONENT MANUFACTURERS

BROADCOM	North America	broadcom.com
COBHAM	Europe	cobham.com
COLLINS AEROSPACE	North America	collinsaerospace.com
DJI	Asia-Pacific	dji.com
ECA	Europe	ecagroup.com
ESTERLINE	North America	esterline.com
FURUNO	Asia-Pacific	furuno.com
GARMIN	North America	garmin.com
GMT	Asia-Pacific	gmtc-global.kr
HEXAGON AB*	Europe	hexagon.com
HONEYWELL	North America	honeywell.com
JRC	Asia-Pacific	jrc.co.jp
KONGSBERG	Europe	kongsberg.com
MEDIATEK	Asia-Pacific	mediatek.com
NAVICO	Europe	navico.com
OROLIA	Europe	orolia.com
QUALCOMM	North America	qualcomm.com
SEPTENTRIO	Europe	septentrio.com
STMICROELECTRONICS	Europe	st.com
THALES AVIONICS	Europe	thalesgroup.com
TRIMBLE	North America	trimble.com
U-BLOX	Europe	u-blox.com

Note: This list does not include system and terminal integrators, and therefore some key industry players may not appear in the list.
** Includes LEICA and NOVATEL*

Receiver industry

The receiver industry in this segment is characterised by little change in the companies that are active. The characteristics historically have been focused on developing receivers that meet high certification requirements governing environmental interference, software performance, and fall back procedures – especially given GNSS's criticality to positioning of aircraft and marine vessels.

This regulatory hurdle also means that innovation and adoption of new technologies will tend to lag behind other sectors, until standards are updated and manufacturers are able to develop new products that comply with the new standards. As such, the path to market has been difficult for new entrants.

Each of the transport sectors has depended on a plethora of different systems, but increasingly there is now dependence on GNSS for the highest levels of performance, whilst integration with sector-specific solutions is maintained. Increased automation also depends on information sharing and data being passed about own position and intentions. The rapid developments in mass-market segments are being utilised by new entrants especially within drones and lower cost aviation, and are challenging the traditional approach that requires certification to support safety-critical applications.

New entrants are firmly targeting the lower cost and less regulated areas of this sector, by using new approaches to ensure safety in the absence of certification, e.g. through techniques such as Specific Operations Risk Assessment (SORA) for drones. As some automotive chips themselves adopt certification standards, this will aid the momentum toward their integration and mitigate the inherently high development costs, long life cycles, and corresponding technology obsolescence, as shorter lifecycles are adopted.

The regulatory environment of safety-critical value chains continues to be influenced by large innovators

The macrosegment is divided into domains with specific regulatory, certification, and operational frameworks. Each domain has its own regulatory and standards bodies, and key players tend to integrate vertically up and down the value chain rather than horizontally. Sector expertise and reputation override economies of scale for these sectors, where the priority on safety means that the cost of specialised products can be accommodated.

This is being challenged by the performance of new chips incorporated into new low-cost products or targeted at the drone industry. At present, the drone industry is a dominant influencer in the regulatory environment. The promise of significant investment and the potential for spillover technologies from other users make this a novel area for testing new approaches to regulation and approving operations dependent on GNSS capabilities.

This promise is, however, constrained by the continuation of historical approaches whereby regulators assess and adapt to these new developments, e.g. by adjusting existing frameworks with new proposals to reap potential benefits.

Given the challenges that changes in frameworks can have for all users, the industry is finding that the new innovators can be useful collaborators to help shape future regulations, and to enable them to support the adoption of innovative technologies within safety-critical environments. This moves standards and specifications to focus on addressing performance, requirements in which GNSS becomes a key component. This is being seen now in the development of standards and the finalisation of sector specific requirements covering Dual-Frequency Multi-Constellation (DFMC) receivers. This is also supported by the European Commission and a key component in the SESAR ATM Masterplan.

STANDARDS DICTATE THE GNSS CAPABILITIES THAT CAN BE USED IN THE SAFETY-CRITICAL MARKET

Overcoming regulatory hurdles

For genuine safety-critical applications, certification is required. Current regulations and standards only mandate use of GPS, meaning that GPS-only receivers are still in the majority. SBAS continues to be essential in delivering the required integrity and as such is included in the majority of receiver models. One of the reasons for the slower acceptance of other GNSS signals could be linked to integrity requirements. The augmentation of GNSS signals through SBAS, and other technique now in development such as ARAIM, are leading to acceptance of augmented GNSS as a suitable means of compliance in all sectors. The adoption of newer GNSS constellations and related systems and techniques within this sector has often been linked to regulatory progress due to safety requirements.

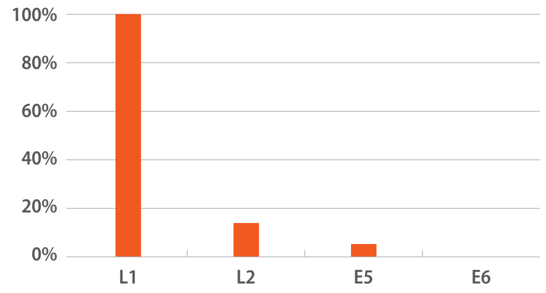
DFMC (Dual-Frequency, Multi-Constellation) standards, in combination with rapidly maturing road, rail, and drone safety-critical applications are set to transform this picture, and are the next anticipated development within the sector. Safety-critical applications, particularly those with higher levels of automation, are increasingly demanding higher accuracy, combined with the traditional priorities of integrity and robustness. This is required as a result of the environments in which they will need to operate. As standards are updated, regulatory processes will be able to adapt and industry will follow with updated certified GNSS receivers supporting DFMC.

Autonomous driving provides a case in point where the stringent regulatory environment of aviation and maritime has not limited adoption in the same way. The operational environment is also completely different to these mature safety-critical sectors, and so are the standards and system requirements. As a result, bespoke receiver architectures are being developed and tested. Naturally these architectures take advantage of DFMC, as well as integrating other sensors directly into the PVT solution.

Liability-critical applications have more freedom to utilise DFMC capabilities and have done so for some time, but only account for a small percentage of the receiver models available. The use of DFMC (or even more frequencies) receivers for non-safety applications within these domains adds pressure to reform standards to exploit their capabilities.

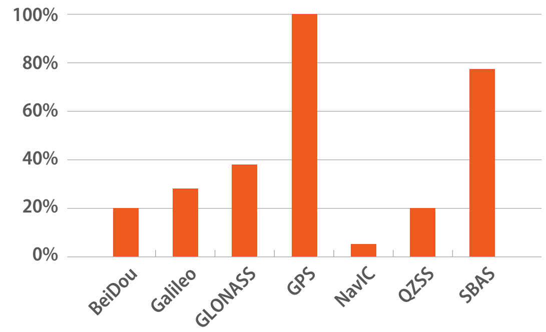
Safety-critical receivers for the rail industry are still only in the development stage, as standards are in development at the time of writing. As a result they do not contribute to the statistics.

Frequency capability of GNSS receivers[1]



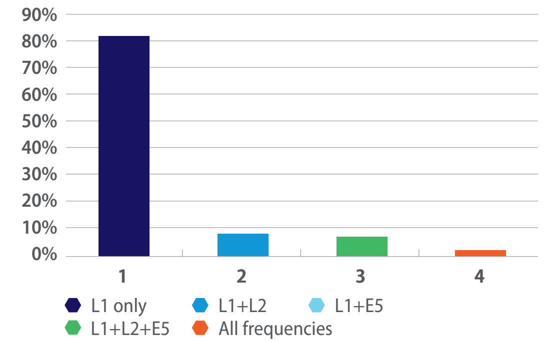
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



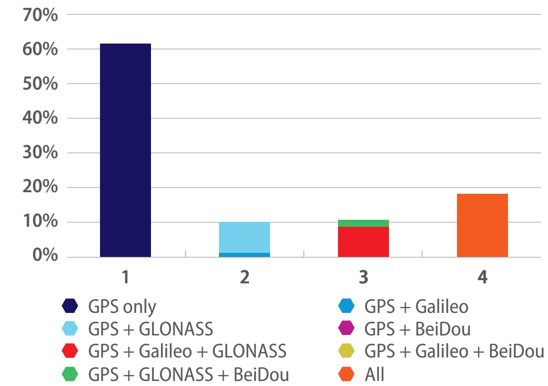
[2] shows the percentage of receivers capable of tracking each constellation

Supported frequencies by GNSS receivers[3]



[3] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 frequencies

Supported constellations by GNSS receivers[4]



[4] shows the percentage of receivers capable of tracking 1, 2, 3 or all 4 global constellations

Disclaimer: The above charts reflect manufacturers' publicly available claims regarding product capabilities, and judgement on the domains to which they are applicable. Use in actual applications may vary due to issues such as certification, implementation in the end user product, and software/firmware configuration.

REGULATION AND CERTIFICATION FOCUS RECEIVERS ON INTEGRITY

Typical state-of-the-art receiver capabilities for the transport safety- and liability-critical devices macrosegment

Features	Aviation	Maritime	Automotive
Number of channels	12-100+	12-100+	32-52
Code/ Phase processing	Code and carrier phase	Code and carrier phase	Code and carrier phase Doppler
Constellations/ Signals	GPS L1	GPS, GLONASS, BeiDou, Galileo, QZSS, NavIC	GPS, GLONASS, BeiDou, Galileo, QZSS, NavIC
Sensitivity (typical)	-135 dBm acquisition -140 dBm tracking	-130 dBm acquisition -135 dBm tracking	-147 dBm acquisition -162 dBm tracking
Multipath rejection techniques	Usually yes	Not documented	Usually yes
SBAS/ A-GNSS readiness	SBAS (E)TSO 145/146	SBAS supported (non-safety of life)	SBAS supported (non-safety of life)/A-GNSS supported
Receiver connectivity	Per ARINC 429	RS422/ NMEA 0183/ NMEA2000	
TTFF	Cold Start: <75s Warm Start: <30s Re-Acquisition: <3 to 10s	Cold Start: <60 to 120s Warm Start: <30s Re-Acquisition: <1 to 10s	Cold Start: <33s Warm Start: <30s Re-Acquisition: <1s
Horizontal accuracy (95%)	GNSS: 5 – 15m DGNSS: N/A SBAS: 3m	GNSS: 2.5 – 13m DGNSS: 0.3 – 5m SBAS: 2 – 8m	GNSS: 2.5 – 13m DGNSS: 0.3 – 0.5m SBAS: 2 – 8m
Vertical accuracy (95%)	GNSS: 10 – 20m DGNSS: N/A SBAS: 4m	GNSS: 4 – 20 m DGNSS: 0.5 – 7.5 m SBAS: 3 – 12 m	GNSS: 4 – 20 m DGNSS: 0.5 – 7.5 m SBAS: 3 – 12 m
Antenna	External	External	External
Standards & Certification	DO-229D, DO-245, DO-246, DO-208 DO-178C/ED-12C, DO-254/ED-80, DO-160/ED-14G, DO-253/ED-88, ED-114A, ARINC743 (E)TSO C115/129/145/146	IEC60945, 61108-1/2/3/4, 61162-1/3, 62288, NMEA0183/2000, RTCM SC104 USCG or Wheelmark (EC MED)	AEC-Q100 ISO16750 ISO26262 ASIL
Form Factor	Complete unit conforming to standard (e.g. 2 MCU) External Antenna Remote CDU	Complete unit with built-in or remote CDU & Ext. Antenna Alt. 'Smart Antenna' incl. receiver with remote CDU	Receiver Chip or Module
Others		Internal Radiobeacon DGNSS receiver	May include up to 6 axis mems

Disclaimer: The above table provides the typical capabilities of a GNSS receiver based on manufacturers' published literature for their latest products. Consequently discrepancies may exist between the installed receivers' characteristics and those stated above.

Traditionally, receivers utilised in this sector have been subject to high levels of regulation and certification. GNSS receivers have become a critical component of electronic systems supporting each element that drives high levels of performance (integrity and accuracy), and the ability to maintain this accuracy in the event of system faults. For example, the latest certified airborne receivers are able to track 100+ GNSS satellite signals in addition to SBAS channels, support the latest in area navigation and surveillance specifications and include features such as RAIM and augmentation. There continues to be a push for dual-frequency to improve resilience.

The same drive for certification and approval exists in the maritime world, but the requirements were linked predominantly to the performance of navigation aids in ports and coastal waters where there would be reception of DGNSS solutions. Standards for GNSS with SBAS receivers for maritime use have lagged compared to aviation, which is why the GSA, EC, ESA and ESSP have drafted 'Guidelines for the use of SBAS in maritime receivers' within RTCM to foster this adoption, and support standardisation activities for SBAS receivers in the maritime context.

There is still an absence of mature GNSS receiver specifications for rail, and hence they cannot be presented in the table opposite. The operational and environmental aspects in rail pose unique challenges compared with aviation and maritime. Reception of GNSS is challenged by terrain, and operation in close proximity to buildings, tunnels, and deep culverts. These limit the line of sight and the number of satellites in view, and hence the availability of GNSS signals with the timeliness required to support all safety applications. The availability of SBAS and DFMC receiver specifications is expected to improve the performance from a rail perspective and is the subject of ongoing research and development.

Both road and rail will benefit from the ongoing developments and tight coupling of multi-frequency GNSS receiver technologies within the high-volume chipsets supporting the trends in automation. Particularly important as part of this evolution is the coupling of navigation and communication capabilities. This coupling benefits all domains in the sector, including surveillance and communication applications where the integration with 5G positioning could be envisaged for drones, road, in and around airports, and in coastal regions. This future usage of multi-frequency receivers will achieve significant improvements in measurement and positioning accuracy, preceded by applications not requiring the full oversight of regulation, and so benefiting from the evolution in capabilities of mass market chipsets.

FOCUS ON DFMC STANDARDISATION

DFMC Receiver Standardisation

The deployment of new constellations with additional signals and frequencies led to the realisation that these could be coupled with the existing core constellations of GPS and GLONASS, introducing the technological concept of Dual-Frequency, Multi-Constellation (DFMC). From a general point of view, a DFMC receiver will acquire more lines of sight (i.e. more satellites) when using several constellations, and benefit from two separate frequency links to each satellite, improving overall availability, accuracy and robustness. The availability of multi-constellation will also provide considerable benefit for receivers that are working in severely obstructed environments, often masking satellite signals.

Galileo is expected to achieve its Full Operational Capacity shortly. GPS is expected to complete its incorporation of L5 later, by 2027 according to current (2020) plans. This implies that full EGNOS DFMC performance will not be available before 2027 at best. Earlier service milestones may offer reduced levels of DFMC service for some user communities including for aviation, if intermediate commitments are published for GPS L5 performance prior to Full Operational Capacity.

As far as SBAS is concerned, SBAS DFMC will enable augmentation of up to four constellations on both the L1 and L5 frequencies. In Europe, next generation EGNOS v3, from version v3.2, will introduce this concept of DFMC and will augment both GPS and Galileo, resulting in more satellites in use. SBAS DFMC will improve accuracy compared to legacy SBAS enabling lower protection levels (contingency levels), and thus more stringent operations could be carried out in maritime (at port entrances when traffic is denser), in aviation and in rail. Also with the use of two frequencies, SBAS DFMC will be more robust to interference, jamming, and ionospheric perturbations. The same applies to the application of DFMC to other augmentations such as ARAIM and GBAS, which are discussed in more detail on page 55.

Currently GPS and Galileo SBAS DFMC is being standardised by ICAO, EUROCAE and RTCA, with joint activity between EUROCAE WG-62 and RTCA SC-159 WG2 on DFMC SBAS Minimum Operational Performance Standards (MOPS). At ICAO, the DFMC SBAS SARPs sub-group has produced a DFMC SBAS technical baseline approved in NSP/5 (Navigation System Panel) in November 2018. The objective is to have complete validation of the DFMC SBAS SARPs by the end of 2020, so that they are effective from 2022. At EUROCAE, WG-62 is now working on an updated MOPS to define the minimum requirements for GPS / Galileo SBAS DFMC receivers. The first version of the MOPS, ED-259, was released in February 2019 with its update available for consultation from the end of 2020.

EDG^{2}E: Equipment for dualfrequency Galileo GPS and EGNOS

DFMC standardisation projects, such as EDG^{2}E, have been funded by the GSA in order to accelerate the introduction of DFMC within the GNSS community.

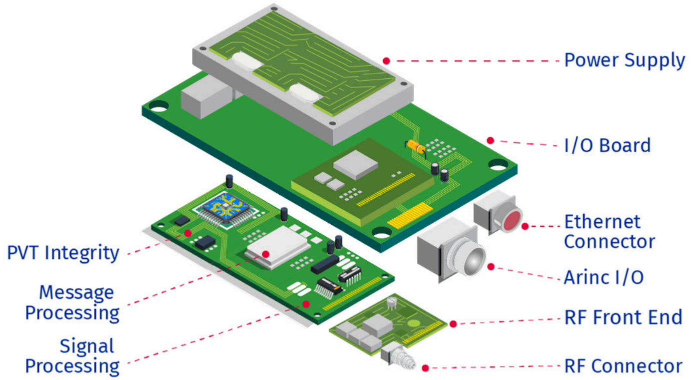
next generation gnss receiver

EDG^{2}E intends to develop a dual-frequency multi-constellation receiver, enabling enhanced navigation capabilities, support standardisation, and certification preparation. It targets applications across aviation, rail and drones.

It is a two-phase project:

1. Phase 1 ended in 2019 and included the development of a software prototype using raw data (measurements and navigation data bits), computing the positioning solution in the different integrity solutions (RAIM/FDE, SBAS L1 and SBAS DFMC) according to the standards developed by EUROCAE WG-62 (ED-259). The software was designed to be compliant with the hardware platform developed in Phase 2.
2. Phase 2 will end in 2021 and is developing the full GPS / Galileo / SBAS dual-frequency prototype, integrating the software modules developed in phase 1, complemented by new functionalities such as the H-ARAIM/FDE capability. Once the verification phase is completed, flight tests will be carried out with the prototype allowing raw data to be stored for further post-processing replay.

Further information is available at: gnss-edge.eu



SEARCH AND RESCUE NOW BENEFITS FROM GALILEO RETURN LINK SERVICE (RLS)

RLS operational capacity

The Galileo Return Link Service (RLS) was declared operational on 21 January 2020. The service, a joint effort between Cospas-Sarsat and the Galileo programme, is free of charge, and available to all Cospas-Sarsat RLS-compatible beacons. The Galileo satellites are able to pick up emergency signals emitted from distress beacons at a frequency of 406 MHz and transmit a Return Link Message (RLM) signal back to the beacon through the Galileo Navigation Message (I/NAV E1).

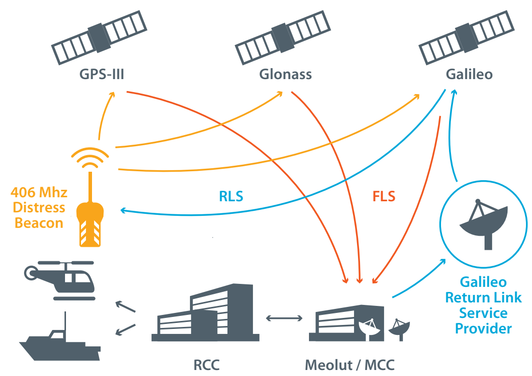
The availability of the Galileo RLS is equally of benefit to both the aviation and maritime sectors. The IMO established in 1988 the Global Maritime Distress and Safety System (GMDSS), with the intention of allowing vessels to be able to send and receive maritime safety information at all times. This reached operational status by 1997. Such a system did not exist for aviation, leading to calls to establish an equivalent given the length of time taken to locate aircraft after air disasters such as AF 447 or MH 370. The result was the establishment of the ICAO Global Aeronautical Distress and Safety System (GADSS). Under the current aircraft tracking standards and recommended practices (SARPs), aircraft under normal flight conditions need to be tracked every 15 minutes. The latest update of ICAO Annex 6 requires autonomous position reporting every minute when the aircraft is in distress. The standard for the distress tracking element of GADSS is planned for implementation by January 2023.

Galileo SAR infrastructure

There are two high level dimensions to the Galileo SAR infrastructure. These consist of service facilities and a core infrastructure consisting of space and ground assets. The space elements of the Galileo SAR consists of 24 Medium Earth Orbit (MEO) satellites arranged in three orbital planes. These satellites are fitted with SAR repeater instruments, enabling them to receive distress signals at 406 MHz, and to retransmit them in the L-band at 1544.1 MHz.

The ground dimension of the Galileo SAR is extensive and consists of numerous interoperable components. These can be broadly grouped into two segments:

Galileo SAR within MEOSAR



1. **Forward Link service** comprising three Medium Earth Orbit Local User Terminal (MEOLUT) facilities which track the Galileo satellites in view, and detect beacon distress alert messages.
2. **Return Link** service which is facilitated through the Cospas-Sarsat French Mission Control Centre and the ground mission segment of Galileo, and uplinks return link messages to the Galileo satellites.

RLS compatible product offerings

Due to the recent introduction of the Galileo RLS, the number of compatible SAR distress beacons available is still limited. Orolia Maritime is the only manufacturer to have released a Galileo RLS Personal Locator Beacon (PLB) for aviation and maritime use. Orolia have worked closely with the GSA on the Galileo RLS project, and were therefore selected as the lead on development of the next generation of SAR distress beacons. As such, the FastFind Return Link PLB is the first PLB of its type on the market. In addition, under the Helios project funded by the GSA, Orolia is developing and has successfully tested EPIRB and ELTs with RLS.

Several other developments are being supported by the GSA through the H2020 and Fundamental Elements programmes, including manufacturers such as ACR Artex, ECA Aerospace, Syrlinks, Marine Rescue Technologies, Ocean Signal and Mobit Telecom.

TAUCETI: Next generation Survival ELT (ELT-S)

The TAUCETI project, lead by Orolia, aims at providing a new range of Survival ELT (ELT-S) for large aircraft cabin crew, and for life rafts equipped onboard aeroplanes or helicopters, integrating Galileo SAR RLS.

The project is defining and developing distress beacons that are compatible with multiple GNSS constellations and meet the latest end-user requirements. The project also includes GNSS & SAR system validation in the field. Certifications for the new Ultima-S range include:

- Medium Earth Orbit Search And Rescue (MEOSAR) Cospas-Sarsat compatibility;
- Navigation Satellite System constellations, including Galileo GNSS navigation data;
- Compatible with legacy LEO- and GEOSAR satellites;
- Optional Galileo RLS automatic acknowledgment service.

The project is moving forward towards mature and certified products in 2021, which will be the first Galileo capable equipment serving the needs of the SAR community and aviation industry onboard a civil aircraft.

Further information is available at: tauceti-gsa-project.eu.

E-GNSS SUPPORTS GLOBAL MONITORING FOR SAFETY AND SURVEILLANCE

In addition to the global monitoring supporting maritime and aviation from a distress perspective, the use of satellite assets coupled with GNSS to support surveillance is increasing in importance and is seen as one possible route to support monitoring of drones. The distinction between the services provided by GMDSS and GADSS and that of a surveillance system is the continuous and real-time aspects of the surveillance system, which can continuously monitor GNSS position reports from space.

For several years there have been initiatives in both maritime and aviation that enable the broadcast of position, track and speed information from vessels and aircraft. The technologies are similar in intent to the Automatic Identification System (AIS) for maritime and Automatic Dependent Surveillance Broadcast (ADS-B) for aviation. The monitoring of the different AIS and ADS-B signals from space already exists, with examples from MarineTraffic.com and more recently the official launch of the Aerion Alert service on 9 July 2019, following the earlier successful operational launch of its service with ANSPs.

Satellite based position monitoring requires full power transmissions from the ground. The improved performance, low cost and DFMC capability of mass market chipsets however is leading to a proliferation of lower cost GNSS receivers, and ADS-B receivers and transmitters targeting drones, sport, general aviation and rotorcraft communities with lower power output settings (e.g. <25 watts compared with 120 watts in certified products) – including that proposed by f.u.n.k.e Avionics opposite – as well as innovations on form factor and installation scenarios. The lower output so far may mean that they are undetectable from a spaced-based ADS-B service such as that provided by Aerion and alternative solutions need to be found.

As the quality and performance of these lower cost products means they will be used on an increasing basis to support reductions in ground infrastructure, greater dependency on GNSS for surveillance and monitoring is expected.

f.u.n.k.e. AVIONICS provides affordable GNSS-based surveillance products for General Aviation

f.u.n.k.e.
AVIONICS GMBH

Similar to road traffic, air traffic in low altitudes is self-organized by the pilots on the 'see and be seen' principle. While airliners are separated by air traffic control using radar technology and instrument flight procedures, all visual flights rely on detection and avoidance based on visual contact between the traffic participants. Observation through the cockpit window, however, is not always sufficient to ensure detection of all nearby traffic. Expensive GNSS-based traffic alert and collision avoidance solutions are available for the air transport sector, but such products are too expensive for many General Aviation participants, a sector which is dominated by private aircraft and aeroclubs.

f.u.n.k.e. AVIONICS has developed and offers a low-cost, portable device called PlaneSight, which uses standard GNSS technology (multi-constellation and SBAS enabled) and combines this with a radio transceiver on the 1090 MHz transponder frequency in one product. PlaneSight permanently measures its position and sends it to the surrounding air traffic as ADS-B messages on 1090 MHz to make itself 'be seen' by other aircraft. Likewise it receives ADS-B messages on 1090 MHz from nearby aircraft and depicts them on an internal or external map display so that the pilot can 'see' all relevant traffic around the actual position. Such devices have been proved to support threat detection and collision avoidance in the SESAR JU GAINS project in 2019, clearly demonstrating that GNSS is contributing to achieve the objectives of a 'Single European Sky'. The PlaneSight product contributes to promote the broad use of this safety enhancing technology 'for everyone'.

Testimonial provided by the company

AUTHENTICATION: A USEFUL TOOL TO PROTECT PNT AGAINST SPOOFING

GNSS spoofing occurs when a fake GNSS signal is transmitted to fool the receiver to believe it is in a different position. Authentication methods can be used to verify the source of GNSS navigation message data. Alongside the availability of more frequencies through DFMC, this makes GNSS more resilient to spoofing attempts. The addition of authentication data within the main Galileo messages provides a way for the end user to verify that the received signal is from a genuine source, and not a spoofed signal. This does not prevent a spoofing attack from occurring, but it does enable it to be detected. Within the Transport and Safety Liability Critical sector, authenticity of PNT becomes more and more critical with increasing levels of automation. This applies across all sectors, and increases the reliance on other communication links that might be used to support the decision-making process.

Galileo authentication

The European Commission is committed to adding authentication as an enhanced feature of Galileo, for Open Service (OS-NMA), and for the CAS (Commercial Authentication Service), to enable the receiver to clearly identify spoofed signals and protect end users. The main complexity of GNSS authentication lies in the broadcast nature of the signals. This means that the authentication of the GNSS signal depends on protection at the satellite end (through encryption or other secure mechanisms) and a test on the authenticity of the received signal on the receiver end.

SBAS authentication

A preliminary concept of operations for SBAS Authentication has been agreed and a small task force set up in October 2019 to finalise SBAS Authentication for the 3rd meeting of the GNSS Sub-Working Group (GSWG) of the ICAO Navigation System Panel (NSP).

The main issue to be solved in the coming months is whether SBAS authenticated data will follow the scheme 'authenticate then use' or 'use then authenticate'. The impact on SBAS continuity, availability and integrity of performance is at stake. Indeed, introducing authentication for SBAS data streams could delay the use of SBAS messages and have an impact upon stringent operations that require low Time To Alert (TTA).

The European Commission is exploring the possibility of improving the security of SBAS navigation data (and signals) through the SPARC project launched under the H2020 Framework Programme, led by Qascom and managed by the GSA. The primary objective of SPARC is to identify how to authenticate SBAS messages, and potentially those GNSS constellations SBAS augments, direct from the satellite. Currently four technical solutions for the authentication scheme are being studied. One solution will transmit authentication messages on the L5-I channel, whereas the other three will broadcast on the L5-Q channel.

DRACONAV: a breakthrough technology to secure GNSS

DRACONAV ICAUNE

GNSS jamming and spoofing are now common threats with the potential for severe impacts on several critical segments of the wider economy and on daily lives. The DRACONAV secure GNSS module has been developed to combat these threats and mitigate their effects, particularly for applications requiring trust, involving financial transactions, or where reputation and privacy are at stake. This encompasses road tolling, insurance telematics, smart mobility, logistics, smart digital tachographs but will also include critical infrastructure network synchronisation, rail operations, and autonomous vehicles in the coming years.

Fully integrated and with several advanced algorithms protecting against GNSS spoofing and jamming, the DRACONAV module offers end-to end security in a format that is autonomous and simple to integrate. The DRACONAV module provides a level of confidence by indicating the trustworthiness of each computed PVT output, and implements security features compliant with REGULATION (EU) No 165/2014 ANNEX I C related to smart digital tachograph. With a compact form factor (22.8 x 21.6 x 3.1 mm), DRACONAV can track several constellations simultaneously (GPS, Galileo, GLONASS, QZSS, BeiDou and SBAS) and supports dead reckoning using embedded 6- axis gyrometers and accelerometers, odometers, or via the CAN bus interface (when embedded in a vehicle). Module outputs are delivered to the application via ISO 7816 secure and/or UART interfaces.

DRACONAV is the first product range of ICaune, a start-up specialised in secure sensors for critical applications. Its unique and powerful hardware and firmware is the result of several years of R&D. The prototype development has been supported by the European GNSS Agency under the H2020 FOSTER ITS project.

For more information on DRACONAV: icaune.com

AUGMENTATION TO ENSURE INTEGRITY AND ACCURACY OF CRITICAL PNT ACROSS ALL SECTORS

GNSS satellites signals can be critically delayed when crossing the ionospheric layer that is located at an altitude between 80 to 800 kilometres. If electromagnetic signals hit the free electrons that move within this dense layer, the overall delay from this perturbation can range from a few metres to several tens of metres. The capability to account for this delay as well as other sources of GNSS error is essential across all transport domains. The use of augmentation is a critical tool to enable the end receivers to provide Position, Velocity and Time (PVT) information at the required integrity and accuracy to support all applications. Various types of augmentation and applications are in use and under development to account for these issues. In the following paragraphs we focus on two such systems in particular; namely GBAS and ARAIM.

Ground-based augmentation for aviation and maritime

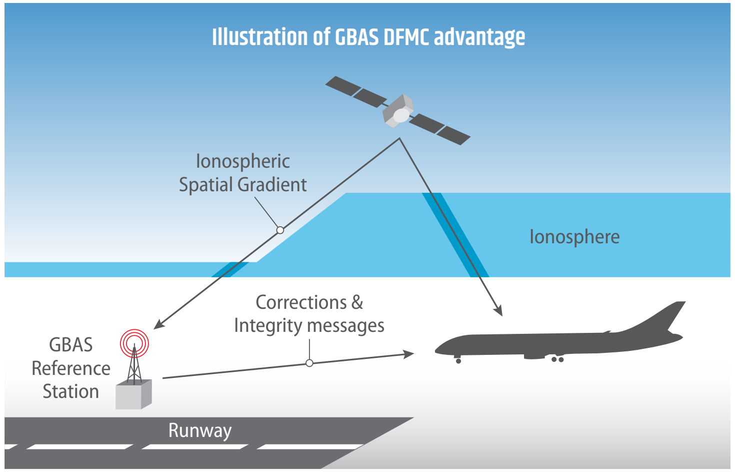
Ground-Based Augmentation Systems (GBASs) are regarded as highly accurate systems and are a modernised development of older DGNSS concepts tuned to address the needs of the aviation community. GBAS consist of two types, referred to as GBAS Approach Service Type (GAST) and addressing single (GAST-D) and dual (GAST-F) frequencies, respectively. Currently only GAST-D stations have been standardised, which allows for a final user GBAS corrected position residual error of one metre. This allows for aviation CAT I minima at best.

Ionospheric disturbance errors are the main contributor to the final residual error, however, and can sometimes be difficult to correct for. This applies particularly in the case of scintillation phenomena occurring mainly at high and low latitudes, during which ionospheric gradients can arise. With the emergence of Galileo and the design of new signals on L1/E1 and on L5/E5, a new concept GBAS GAST-F (i.e. GBAS DFMC) is being developed.

Indeed, GBAS that provide augmentation to Galileo and GPS on L1 and on E5 signals could have the potential to overcome strong ionospheric perturbations and improve aviation minima.

The ionosphere is a dispersivemedium, meaning that two frequenciescrossing the layer will get two different delays. This enables a DFMC receiver to estimatethe ionospheric error precisely and mitigate it.

In early 2018, the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) published 'Guidelines G-1129 on the Retransmission of SBAS Corrections using MF Radio beacon and AIS'. The guidelines, drafted in conjunction with the GSA, provide information for any maritime authority to implement SBAS information as the source of corrections to be transmitted by their shore infrastructure, either IALA radio beacons or AIS stations. Following a successful GSA pilot project EGNOSforATON, six countries have already implemented retransmission of EGNOS corrections using either IALA beacons or AIS stations (France, Spain, Germany, Hungary, Latvia and Estonia) to date.



Advanced Receiver Autonomous Integrity Monitoring (ARAIM)

ARAIM attempts to estimate an upper boundary for GNSS ranging errors, which in turn translate to positioning errors. It is being developed within the aviation context, where GNSS is currently the only means of supporting certain operations. The potential benefits of ARAIM however extend beyond aviation and are equally applicable to the maritime and rail communities. Users in both segments typically operate in areas where they are unable to receive signals from land-based augmentation systems. ARAIM is therefore considered as part of a more complex integrated solution with multi-sensor fusion, also in autonomous vehicles.

The EU-US WGC ARAIM technical sub-group has provided several reports detailing its vision of an evolution of the ICAO Aircraft-Based Augmentation System (ABAS) RAIM implementation in a DFMC context. This ABAS evolution is referred to as ARAIM. The main objective of the ARAIM activity is to determine an appropriate airborne integrity monitoring algorithm to sustain ABAS/RAIM operations with the introduction of additional constellations (Galileo, BeiDou) and frequencies (L1 and E5), along with maintaining maximum operational benefits.

Standardised RAIM algorithms as currently integrated into aircraft provide integrity monitoring capabilities which sustain RNP 0.3 NM and Non-Precision Approach operations. The modernised ARAIM concept takes advantage of the new constellations and the iono-free solution from two frequencies. ARAIM is targeting for horizontal service (H-ARAIM) RNP 0.1, and for vertical service (V-ARAIM) a CAT I precision approach (also known as LPV 200) at a global level.

ARAIM standardisation is at an early stage with prototyping ongoing for GPS and Galileo; nevertheless, the third version of the draft ARAIM Standards and Recommended Practices (SARPs) was circulated during GSWG/3 (GNSS Sub Working Group).

The main issue to be addressed lies in the standardisation of the Integrity Support Message (ISM), which is a channel that broadcasts messages containing parameters such as the probability of satellite failure or of constellation failure. This information is used in the computation of protection levels. As there will be a dedicated ISM per constellation, the ICAO need to have a consolidated version of core constellation SARPs and confirmation that the performance commitments published in the core constellation specifications are firm prior to freezing requirements for the ISM. Work is ongoing with the development of the Minimum Operational Performance Standards (MOPS) and will continue beyond 2020.

DRONE REGULATIONS AND LARGE DEMONSTRATION PROJECTS SUGGEST INCREASED INTEGRATION

Regulations beginning to enable the market further

Since GNSS User Technology report issue 2, regulations EU 2019/947 and EU 2019/945 have defined the rules and procedures for operations of unmanned aircraft and the technical requirements for drones operating within the EU, respectively. The European Union Aviation Safety Agency (EASA) intends to support the drone industry by fostering particularly open and specific categories of drones, with EU Member States implementing the rules specified under these regulations. The requirement for Direct Remote Identification under EU 2019/945 could impose a performance requirement on GNSS signals relating to positioning of a drone in the air.

As of September 2020, January 2021 is the official deadline for Member States to implement these new EU rules. In order to better understand these complex rules, EASA issued Guidance Material (GM) and Acceptable Means of Compliance (AMC) in October 2019. Meanwhile EASA has published 'Standard Scenarios' which enable UAS (Unmanned Aircraft System) Operators to simply declare an aerial operation with low risks to their civil aviation authority, rather than submitting and waiting for approval.

This is expected to have a major impact on the EU drone market, supporting the diversity of services on offer and builds on the EC initiative to develop Urban Air Mobility (UAM). It represents an opportunity for smart cities to solve urban congestion, reduce fossil energy consumption, and benefit from the new regulations to boost Air Taxi, Air Metro and logistics by drones in major cities. As part of the integrated transport picture, this will also increase the demand of geolocation.

DELOREAN: Drones and E-GNSS for LOw aiRspacE urbAN mobility

DELOREAN HORIZON 2020

As of January 2020, the GSA is supporting the Delorean Project which aims to test E-GNSS capabilities supporting future urban air services such as Urban Air Mobility, by developing experimental avionics that benefit from EGNOS and Galileo differentiators. The project responds to user needs by providing innovative mobility solutions as real alternatives to traffic congestion in urban environments.

The project will also develop an urban lab to facilitate testing of innovative mobility concepts and is intended to contribute to the integration of E-GNSS in future standards and regulations to support UAM.

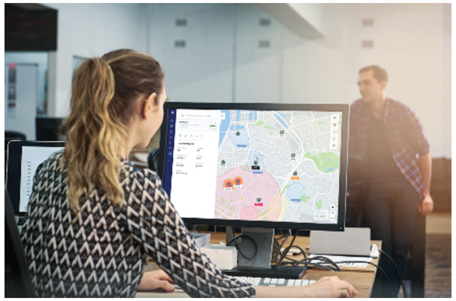
Further information can be found at: pildo.com/approaching-the-future-urban-sky-with-the-delorean-project.

E-GNSS aids safe integration of unmanned aircraftin very low-level airspace

UNIFLY

As unmanned air traffic increases exponentially, maintaining safety is of paramount importance. E-GNSS offers accuracy, reliability and integrity for drone flights operations. The Unmanned Traffic Management (UTM) system displays tracking data in real-time.

Leading UTM provider Unifly contributes to several ambitious E-GNSS projects for the GSA and ESA in 2020. The TRACE project, funded by GSA Aviation grants, develops an EGNOS-based smart beacon to fulfil requirements for drones. It integrates real-time positioning, Line of Sight (LOS) communication and anti-collision lighting. The SUGUS project promotes the use of EGNOS and Galileo (E-GNSS) in the drone services market.



Unifly provides both projects with a UTM Broadcast Location and Identity platform (BLIP). Project partners can prepare and validate their flights, monitor ongoing flights and integrate the real-time tracking and e-identification information. The Unifly platform facilitates the operational use of E-GNSS by the operators as well as the situational awareness by aviation authorities. Unifly's BLIP enriches the UTM platform with location and identity information. BLIP complies with EU legislation and combines GNSS tracking and e-identification to support the safe integration of unmanned aircraft. It transmits tracking data to the UTM platform over the LTE 4G network. Remote identification, 3D location and take off position are broadcasted via Bluetooth to the mobile app.

Testimonial provided by the company

INTEGRATED NAVIGATION SOLUTIONS ARE KEY FOR ENABLING FULL AUTOMATION

Automation of marine vessels

Autonomous Surface Vessels (ASV) are increasing in relevance and are at the forefront of maritime technology. There are numerous factors involved for the successful implementation and operation of an autonomous maritime navigation system. This includes not only a suite of sensors and receivers, such as cameras, radar, LIDAR, acoustic, INS and GNSS to provide safe positioning and situation awareness, but also suitable communication means for traffic management and remote control / operation of the vessels. This latter point is more critical on smaller vessels, where limitations in size, weight and power can restrict the size of antenna carried, and therefore inhibit the extent to which they can communicate. One workaround for specific tasks is edge computing, where mission-oriented processing and analysis is carried autonomously on-board and only processed information need to be transmitted.

Integration and benefits of an Inertial Measurement Unit (IMU)

GNSS will remain the primary source of position information on an autonomous or semi-autonomous vessel as this technology is seen as affordable, accurate and reliable; also integration with augmentation sources removes most of its vulnerabilities. Such augmentations, possibly including EGNOS / EDAS or coupling with IMU(s), are needed to enhance the accuracy and integrity of vessel positioning.

A particularly important case of integration is the coupling of GNSS with an IMU, which offers multiple benefits. It improves the overall navigation system through the ability of the Inertial Navigation System (INS) to provide position and velocity estimates at very fast rates and very low noise. In a tightly coupled INS / GNSS system (see page 26), the combined performance exceeds that of the individual components, permitting fewer than four satellites to play a role in the final navigation solution. Furthermore, an INS has the ability to provide additional automatic warnings that other sensors, such as GNSS, have failed or are operating at reduced accuracy. Such warnings add an extra layer of safety and integrity.

Finally, if there was a failure in the GNSS receiver or other infrastructure, an IMU is entirely autonomous, and as such does not need to send or receive signals that can be blocked or interfered with. Since INS suffers from deterioration of accuracy and position drift over time, however, autonomous operations can be maintained only for limited duration depending on the quality ('grade') of the IMU and on the required accuracy for the operations.

Hull 2 Hull

HULL TO HULL HORIZON 2020

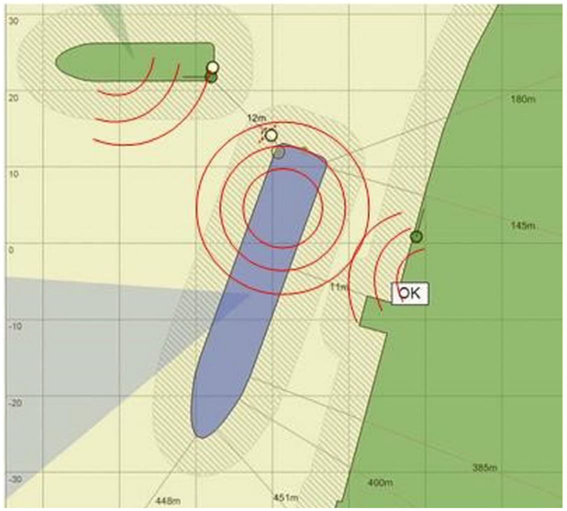
The Hull 2 Hull (H2H) project combines sensor information from LiDAR and IMU with the Galileo and EGNOS systems to generate digital models of the vessel and surrounding objects of interest, and to estimate the accuracy of the location and an 'uncertainty zone' for each object.

These uncertainty zones are multi-band zones around the vessel or object of interest. When the uncertainty zones overlap, warnings are given to the navigator, as well as a suggested course of action. These warnings progressively become more urgent, depending on the proximity and extent of the overlap.

The system was successfully tested and demonstrated in early and mid-2020 in three areas:

- Trondheimsfjorden in Norway, utilising two Kongsberg Seatex test vessels.
- Kanaal van Leuven in Belgium consisting of two demonstrations: a lock passing, and docking. This demonstration utilised 1/8 scale models.
- Kanaal Dessel Kwaadmechelen in Belgium, where a barge was used to demonstrate auto-mooring capability.

Further information is available at: sintef.no/projectweb/hull-to-hull



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RAILWAYS WILL TAKE ADVANTAGE OF TECHNOLOGICAL EVOLUTIONS FOR WIDER AND BETTER SERVICES

GNSS is currently used for railway services around the world

The adoption of GNSS in rail is increasing all around the world. Rail users face similar challenges compared to other ground transportation modes; increasing requirements versus local effects that reduce performance.

Railway needs can be classified into two groups depending on their safety requirements. For non-safety relevant applications, stakeholders continue to equip their fleets with GNSS receivers utilising EGNOS/EDAS/multi-GNSS and Galileo OS-NMA to support improved supply chain visibility for logistics service providers and their customers, traffic management performance, and passenger information systems.

Safety-critical applications mainly concern signalling and train control. Rail network topologies and the rules applied for ensuring safe train circulation strongly differ depending on the continent. Europe has developed the European Rail Traffic Management System (ERTMS) for a harmonised system between countries, and the USA has developed Positive Train Control (PTC). Universally, rail traffic management consists in ensuring the circulation and safety of several trains along the same 1D route utilising train position data based on absolute location (e.g. by balises), plus a safety distance measured with respect to the absolute location (by the odometer). The 1D operational constraint generates very high performance requirements for positioning in terms of accuracy, but even more so for integrity, because the only applicable procedure to avoid a potential accident is braking. These needs cannot currently be met solely by GNSS technology. For both safety-critical and non-safety critical options, users face the lack of GNSS-related standards and specifications in terms of accuracy, integrity or safety assessment methodologies. The definition of rail receiver guidelines is a work in progress, with the continuing preparation for possible inclusion of EGNOS augmentation functions in the upcoming evolution of ERTMS TSI in 2022.

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To date, most systems use Commercial Off-the-Shelf (COTS) chipsets and investigate how to ensure their performance in the rail environment with hybridisation, redundancy or mitigation schemes. Performance will improve as a result of adoption of multi-constellation, multi-frequency receivers as well as Galileo authentication to prevent spoofing. Systems will need to be assessed by independent notified bodies before deployment.

Ongoing studies investigate EGNOS requirements for rail as well as the possible use of EURORADIO to transmit EGNOS data to the train.

When ready, the deployment of fail-safe GNSS-based solutions for positioning will contribute to rail modernisation, increased maintenance efficiency, facilitate ERTMS deployment and reduce overall costs for train signalling.

GNSS receiver use cases in safe applications

The European rail stakeholders are continuing their efforts for GNSS introduction in the ERTMS. Virtual Balise Transmission System (VBTS) architecture has been developed, where a physical balise of the existing Eurobalise Transmission System is simulated by GNSS-based location. The architecture defined in the Shift2Rail (X2Rail2) project, ensures availability and safety even in the presence of local effects common to every land transportation system, with fault detection and exclusion (FDE) mechanisms and RAIM-like algorithms. The GSA H2020 ERSAT GGC project developed a methodology to characterise the local effects along a line as a tool for VBTS design. For further applications and other train subsystems such as Automatic Train Protection (ATP), the ongoing work consists in developing a continuous, accurate and safe positioning solution, capable of providing travelled distance, speed and absolute position of the train.

ERSAT GGC

HORIZON 2020 — ERSAT GGC

This project, which ended in November 2019, finalised a safety and hazard analysis of the Enhanced ERTMS Architecture based on GNSS and proposed a methodology for Track Survey and Track Classification. A procedure and associated toolset have been developed for the classification of track areas as suitable or not suitable for the Virtual Balise placement, depending on the occurrence of multipath, satellite visibility, and interference.

Further information is available at: ersat-ggc.eu.

X2Rail2-WP3: development of a fail-safe positioning architecture

Shift2Rail — X2RAIL 2

The objective of X2Rail2-Work Package 3 was to implement and support the main goal of S2R TD2.4 (Fail-Safe Train Positioning - including satellite technology), which is to achieve a significant reduction of the use of traditional train detection systems in ERTMS/ETCS owing to an absolute and safe train positioning system.

The project proposed an architecture for virtual balise operation and conducted research into defining an enhanced safe train positioning subsystem to be utilised by other train subsystems, for longer term use such as odometry enhancement. It also performed a Cost Benefit Analysis (CBA) and drafted guidelines for railway MOPS.

Further information is available at: shift2rail.org.

IN THE ROAD SECTOR, 5G SUPPORTS THE MOVE TOWARDS FURTHER AUTOMATION

Increasingly vehicles are connected to the Internet and to each other as automotive technology advances towards higher levels of automation. Driver-assisted and driverless cars need real-time safety systems that can exchange data with other vehicles and fixed infrastructure around them. This drive towards full automation and ambient intelligence generates increased communication needs and poses significant challenges to the underlying communication systems, as information must reach its destination reliably within a short time frame; beyond what current (up to 4G) wireless technologies can provide.

5G is expected to enable low-latency communications between vehicles (V2V), between vehicles and roadside infrastructure (V2I), with a back-end server (e.g. from a vehicle manufacturer or other mobility service providers), with the Internet (V2N), with a pedestrian (V2P), and in other use case scenarios. As such, 5G is a key enabler of future mobility and transportation services.

Three examples highlight that the mobile communications industry and the automotive industry are interwoven, jointly providing new capabilities and functionality for upcoming road safety services and future driving. These use-cases also present the way in which they cooperate; the automotive industry-composed consortium **5GAA**, the H2020 project **5GCAR** and the case study **EMERGE.**

5GAA

In 2016 key players of the automotive, technology, and telecommunications industries established the 5G Automotive Association (5GAA) global organisation. 5GAA provides a platform for cooperation and common vision sharing in relation to the development of 5G-based end-to-end solutions, focused on the mobility and transportation sector.

More than 130 companies have now joined 5GAA, including automotive manufacturers, tier-1 suppliers, chips/communication system providers, mobile operators and infrastructure vendors.


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More information at: 5gaa.org

5GCAR

5GCAR (*5gcar.eu*) is a 26-month project funded by the European Commission, in the frame of the 5G Infrastructure Public Private Partnership (5G PPP) that ended in June 2019.

5G's low latency and high bit-rate as enablers of connectivity, autonomy, and provision of safety services were at the core of the research of 5GCAR. Specifically, technology components for the broadcast of assisted GNSS data through 5G communications were developed, for enabling enhanced positioning in the cases of automated vehicles and vulnerable road user protection.

An end-to-end optimised 5G network for V2X communications (vehicle-to-pedestrian, vehicle-to-vehicle, vehicle-to-network, vehicle-to-mass-transit and vehicle-to-infrastructure) was designed, developed and tested, with recommendations for a path to global deployment/adoption and standardisation of the developed solutions made.

Further information is available at: 5g-ppp.eu

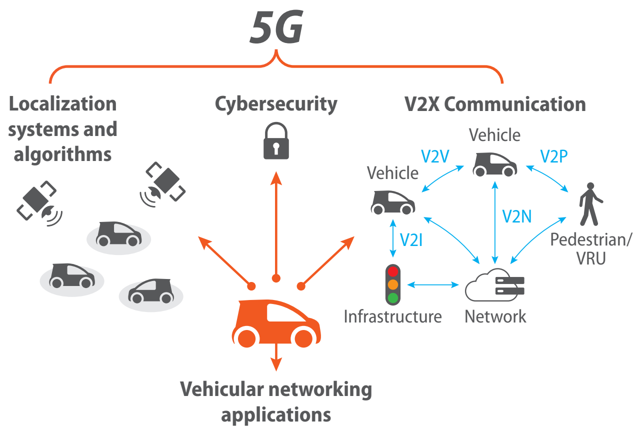
EMERGE

EMERGE is an Italian national initiative, exploring the possibilities offered by combining GNSS and 5G, with a focus on connected vehicles. Launched in January 2020 for a duration of 36 months, the project will develop a solution integrating GPS-Galileo-based multi-constellation and multi-sensor fusion for localisation, 5G enabled V2X vehicular communication technologies, and cybersecurity techniques for protecting all vehicular communications.

The aim of EMERGE is the development, prototyping and test of innovative solutions to allow connected vehicles to operate in daily or emergency scenarios. In particular:

- Geo-localisation of the vehicle with satellite multi-constellation (GPS+Galileo), augmentation algorithms and data-fusion with on-board sensors;
- Communication inter and intra vehicles by integrating cellular, satellite public networks, and 5G;
- Cybersecurity for enhancing security on intra and inter vehicular communications and ensuring integrity on data for vehicle positioning;
- Cloud/Edge computing by developing and implementing algorithms to identify and avoid potential hazards.

Field trials will be carried out with commercial vehicles equipped with a prototype in the city of L'Aquila, where a 5G technology experimentation is underway considering two operational scenarios (nominal/everyday and emergency situations).



THE ROLE OF GNSS IN DIGITAL TRANSFORMATIONS FOR FREIGHT TRANSPORT AND LOGISTICS

Beyond connected vehicles, the automotive sector is already a significant user of wireless connectivity in multimodal transport and logistics hubs such as ports, airports, or railways stations.

Digitalisation of freight transport documents

Freight transport documents feature information and data relating to goods, including means of transport, origin, authentication, and access to ports or customs clearance. The EU regulation on the digitalisation of the freight transport information (eFTI Regulation) published in 2020, provides opportunities to streamline the exploitation of the large amount of data produced along the logistics chain, to leverage the contribution of IoT in generating such information, and for cloud platforms to manage and process this data.

The benefits expected from such digitalisation, however, strongly rely on a stable communications backbone, in which reliability and trust of data are imperative. The requirements here include large-file and real-time exchange of data from multiple domains and stakeholders (transportation, public administration, emergency services, weather sensing, etc.). This requires connectivity to infrastructure that can be enhanced by 5G. Even where the bandwidth requirements of such communications are limited, the latency and reliability requirements – particularly when these communications become ubiquitous and essential to consumer and business life – will likely be better served by 5G than by current wireless protocols.

Today's 3G and 4G mobile networks were developed with consumer voice and data in mind. Machine to-machine communications have only recently acquired prominence. Alternative solutions using dedicated Low Power Wide Area Networks (LPWANs) deployed for the IoT (SigFox, LoRa) are not largely applied in freight transport and logistics.

Crucially, 5G's high bit-rate could enable the upload and download of high volumes of transport-related data or the upload of sensor data.

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The role of GNSS authentication in freight transport and logistics

For digital freight transport and logistics, GNSS-based technologies and solutions gather position and timing information that, combined with inputs from other sensors, can enhance the supply chain visibility, safety and security owing to a wider availability of data in electronic form. Considering the liability characterisation of many transport or logistics operations, the quality of the positioning, velocity and timing information (in terms of accuracy and reliability), and the reliability of the sources (in terms of trust and authenticity) play an important role. The use of multi-GNSS solutions and authenticated positioning support the development of tools and measures to ensure the quality of exchanged digital data, the relevant trust and reliability, and official electronic validation.

GNSS authenticated positioning can allow involved entities (economic operators and authorities) to evaluate the quality of the exchanged data, identify their source, and eventually assess the trust that can be placed in them.

Many applications oriented to authorities and governmental users are set to benefit from such confidence appraisal include law enforcement, emergency services in case of accidents, search and rescue, remote control of access through gates, sensitive logistics hubs, and elaboration of statistics.

While the benefits generated are primarily expected for liability and safety implications, widespread availability of trusted position and time information is also expected to result in commercial benefits for business stakeholders, e.g. by fostering the adoption of tracking and tracing solutions, and for electronic transport documents.

For customs operations, various technological solutions are adopted, generally identified as 'intelligent cargo'. These include GNSS combined with advanced sensors and tracking devices, which are becoming more sophisticated and integrated with other sources, generating a very large amount of data.

Risk assessment tools, blockchain, and artificial intelligence solutions can take advantage of the availability of high-quality position information for prompt alarm raising in case of anomalous conditions, for support to decision-making, risk prevention and mitigation, emergency activation, and for generation of performance indicators and statistics.

E-GNSS CONTRIBUTES TO SAFE AND EFFICIENT TRANSPORT

Galileo

The improved positioning and navigation performance offered by Galileo supports users in the transport sectors of aviation, maritime, rail and road, to achieve the performance required by safety-critical systems, often driven by rigorous standards and typically subject to certification. Accuracy and availability are already improved significantly by the availability of additional GNSS satellites from Galileo. Safety-critical transportation solutions indeed need to be able to function at any point in time; the availability of a greater number of GNSS satellites helps to ensure that valid positioning information is computed even in challenging operational environments. Furthermore, Galileo HAS will ensure the enhanced accuracy required for applications such as autonomous driving. Nevertheless, the key contribution of Galileo to the applications featured in this macrosegment is in terms of robustness and resilience of the receivers employed. The features of the Galileo signals, data and frequencies make spoofing and jamming easier to detect, while the Galileo differentiators, including OS-NMA and CAS, ensure the signals have not been tampered with.

EGNOS

The main added-value from EGNOS is the provision of integrity and continuity, making it an essential addition in domains such as aviation. Here the service is a key enabler of Performance Based Navigation (PBN) routes and procedures, and lives might be endangered if the location signals are incorrect. As a result of EGNOS ensured integrity, users can assess the trust that can be placed in the fidelity of the location information supplied by the navigation system. Additionally, EGNOS provides timely warnings when the system or its data should not be used for navigation. EGNOS also provides a positive contribution in terms of accuracy achieved, owing to the differential corrections broadcast.

E-GNSS Contribution to Key Performance Parameters

Key Performance Parameter (KPP)*	EGNOS contribution	Galileo contribution
Accuracy	⬢⬢⬡	⬢⬢⬢
Availability		⬢⬢⬡
Continuity	⬢⬢⬢	⬢⬢⬡
Integrity	⬢⬢⬢	⬢⬢⬡
Robustness	⬢⬢⬡	⬢⬢⬢
Time To First Fix (TTFF)		⬢⬢⬡

* The Key Performance Parameters are defined in Annex 3

⬢⬢⬢ Major contribution, capable of enabling new GNSS applications
⬢⬢⬡ Medium contribution, enhancing the user experience
⬢⬡⬡ Low contribution, performance improved but no major difference at user level

TRACE

Started in 2019, TRACE is a two-year project funded by the GSA which promotes the use of EGNOS by developing a smart beacon to increase the safety levels of Very-Low-Level (VLL) operations, supporting the development of this new aviation sector. The project aims to:

- Facilitate the integration of drones into the initial layers of U-Space services, therefore enabling registration, identification, geofencing and real-time tracking of drones as per European regulations, and;
- Increase the situational awareness of General Aviation pilots of drone operations around their positions.

The project aims to utilise the improved accuracy from EGNOS to enable a reduction in separation among drones and utilise the vertical positioning accuracy to open the possibility of two flight levels, with VLL flights managed by U-Space. The increasing use of EGNOS is expected to provide sufficient integrity to avoid the need for U-Space service providers to rely on additional RAIM or commercial services to complement positioning solutions.

Further information is available at: trace-project.com

HIGH-ACCURACY DEVICES

THE HIGH-ACCURACY SECTOR PUSHES THE BOUNDARIES OF PERFORMANCE AND OPENS AVENUES TO MANY OTHER SEGMENTS

Characterisation of the macrosegment

Whether operating in difficult environments (such as marine surveying and engineering) or carrying out activities essential for the economy and society (such as precise seeding in agriculture), high-accuracy professionals are pushing the boundaries of GNSS performance. To that end, they rely on advanced receiver capabilities and a multitude of augmentation services and techniques, placing them at the frontier of fast, reliable, and accurate GNSS solutions. Whilst each professional application is characterised by different operational conditions and consequently, different user requirements, several trends apply in equal measure, transforming the high-accuracy sector as a whole. This includes the application of multi-constellation, multi-frequency capabilities and the continued digitalisation of services. It also entails increased reliance on sensor fusion and advanced data exploitation techniques supported by AI.

Agriculture

Agriculture continues to benefit from precise GNSS-positioning as the centrepiece of a multitude of activities. From the accurate steering of tractors to the application of inputs where, when, and how much as is needed, GNSS helps farmers achieve greater profitability, comply with regulations, and protect the environment. Combined with Inertial Navigation Systems (INS), proximal (e.g. hyperspectral cameras) or remote sensing platforms (e.g. earth observation satellites), and exploited in a fully-digitised, AI-backed paradigm, GNSS drives the changes that are transforming the agricultural sector. Swarms of robots performing tedious operations and drones scouting over the fields are no longer science fiction, nor an R&D-only scenario, but rather an emerging GNSS-enabled reality.

Geomatics

Geomatics experts, whether land and marine surveyors, or construction and mining site managers, all demand and seek to benefit from the full strength of GNSS-enabled high-accuracy solutions. With multi-constellation, multi-frequency receivers being an absolute pre-requisite and with advanced correction services continuously evolving, geomatics drives the fusion of data collected by different sensors and processed using AI, Machine Learning and Big Data techniques. As high-accuracy geomatics solutions are increasingly making inroads into mass-market sectors (e.g. autonomous driving), so do mass-market devices become increasingly able to perform low-end mapping and surveying activities.

Key performance parameters for high-accuracy devices

The key performance parameters are highly dependent on the specific application in question:

1. **Accuracy** requirements vary from metre to millimetre levels for different operations. It is achieved by deploying multi-constellation and multi-frequency receivers and utilising real-time kinematic (RTK), precise-point positioning (PPP), space-based augmentation services (SBAS) or combinations thereof.
2. **Availability** may become critical, especially in attenuated environments or rural areas.
3. Improved **Time-To-First-Fix** and (re)convergence time is translated into reduced overall time spent on a geomatics project and subsequently, to reduced costs.
4. **Integrity** is of paramount importance when safety-of-life (and equipment) considerations apply (i.e. machine control), and is relevant for capital intensive applications (e.g. mining and offshore applications).
5. **Continuity** is important for operations in which minimising operational downtime due to obscured satellite reception is critical (e.g. marine engineering).

High-accuracy devices key performance parameters

Key Performance Parameter (KPP)*	High-Accuracy Devices
Accuracy	High priority
Availability	High priority
Continuity	High priority
Indoor penetration	Medium priority
Integrity	High priority
Latency	Medium priority
Power consumption	Low priority
Robustness	High priority
Time-To-First-Fix (TTFF)	High priority

High priority; Medium priority; Low priority

* The Key Performance Parameters are defined in Annex 3

NEW ASIA-PACIFIC ACTORS ARE JOINING TOP COMPANIES ON THE WORLD STAGE

Main actors in the high-accuracy theatre

Applications that require pinpoint GNSS accuracy are inherent for a vast array of professional segments for land-based, water-based and airborne operations.

Geomatics is a large and complex segment that incorporates high-accuracy GNSS solutions for cadastral, construction, mine and marine surveying, machine control, mapping and GIS, Continuously Operating Reference Stations (CORSs), original Equipment Manufacturers (OEM) chipsets, as well as GNSS-enabled sensor amalgamations such as mobile mapping systems, aerial photogrammetry and LiDAR drones. For all land-based applications, Hexagon and Trimble continue to hold more than half of the total market share, followed closely by Topcon. Asia-Pacific companies such as Hi-Target, BDSTAR, Hemisphere, and CHCNAV however, combine now for more than 10% of the market in geomatics. Marine surveying primarily utilises an integration of GNSS with inertial measurement units (IMUs) and bathometers to provide seabed mapping, oil and gas fields surveying, dam and mine tailing floor monitoring, dredging, construction, and pipe and cable laying. Trimble and Kongsberg are among the leading manufacturers of dedicated marine surveying GNSS instruments.

Agriculture as a sector is primarily investing in GNSS-based automated steering and field GNSS receivers. The segment remains of primary interest for Hexagon, Trimble, Topcon and John Deere, but some newcomers with noticeable market share have emerged including the U.S. based company Raven Industries.

The whole industry traditionally collaborates with local, regional and global land- and satellite-based correction services. The top component manufacturers in geomatics and agriculture produce dedicated receivers for CORS stations, while also operating proprietary terrestrial and space-based augmentation systems, which in turn are increasingly used in mass market and other segments.

Leading component and receiver manufacturers

AGJUNCTION	North America	*agjunction.com*
BDSTAR (UNICORE)	Asia-Pacific	*bdstar.com*
EOS	North America	*eos-gnss.com*
HEXAGON AB (LEICA, NOVATEL)	Europe	*hexagon.com*
HI-TARGET	Asia-Pacific	*hi-target.com.cn*
HUACE (CHCNAV)	Asia-Pacific	*chcnav.com*
JAVAD GNSS	North America	*javad.com*
NAVCOM (JOHN DEERE)	North America	*navcomtech.com*
KONGSBERG	Europe	*kongsberg.com*
RAVEN INDUSTRIES	North America	*ravenprecision.com*
SEPTENTRIO	Europe	*septentrio.com*
TOPCON	Asia-Pacific	*topconpositioning.com*
TRIMBLE	North America	*trimble.com*
UNISTRONG (HEMISPHERE, STONEX)	Asia-Pacific	*unistrong.com*

RECEIVER CAPABILITIES ARE STEADILY EVOLVING TOWARDS EXPLOITING ALL AVAILABLE CONSTELLATIONS AND ALL AVAILABLE FREQUENCIES

Multi-constellation adoption

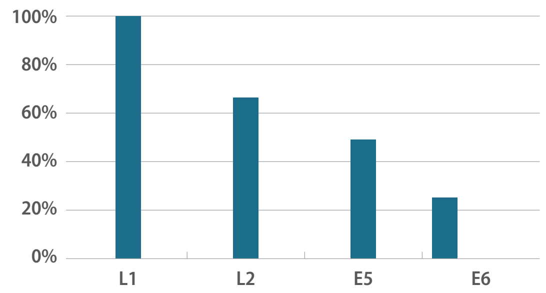
The stringent performance requirements for a wide range of high-accuracy segments translate into a need for increased availability of satellite signals and consequently, faster Time-To-First-Fix (TTFF), improved positioning accuracy, better satellite geometry, and better coverage. This drives the wide adoption of multi-constellation capabilities at receiver level, virtually in all subsegments under high-accuracy. Thus more than 70% of GNSS receivers can process signals from all four major constellations. By contrast, fewer than 10% of receivers only track the satellites of a single constellation.

Multi-frequency adoption

Typically high-accuracy device users seek to exploit the full breadth of capabilities unlocked by multi-frequency receivers. By comparing the GNSS signal delays at different frequencies, receivers can correct for the impact of ionospheric errors. Owing to the added availability of complementary modern signals, primarily E5 and E6, users can achieve significant improvements in positioning accuracy. Finally, multi-frequency receivers reduce vulnerability to interference. All this has led to a significant rise in the number of receivers supporting all frequencies to 25%, as compared to only 5% two years ago. This trend also supports the proliferation of augmentation techniques such as PPP-RTK, which are less reliant on existing ground infrastructure than RTK and can provide faster convergence times than PPP.

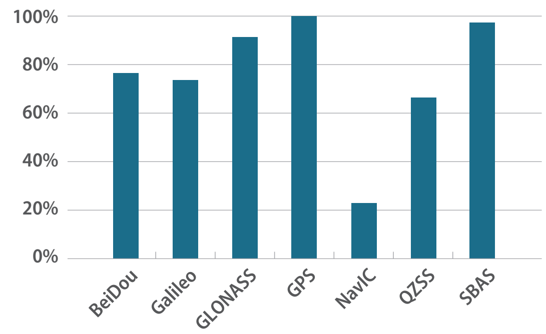
Another important trend is the increased adoption of E6, with currently more than 20% of receivers able to process these signals, compared to less than 5% two years ago. This paves the way, for instance, for the implementation of Galileo-enabled value-added services, the High-Accuracy Service (HAS) transmitting PPP corrections in E6-B, and the Commercial Authentication Service (CAS), giving access to encrypted codes on the E6 signal pilot component (E6-C).

Frequency capability of GNSS receivers[1]



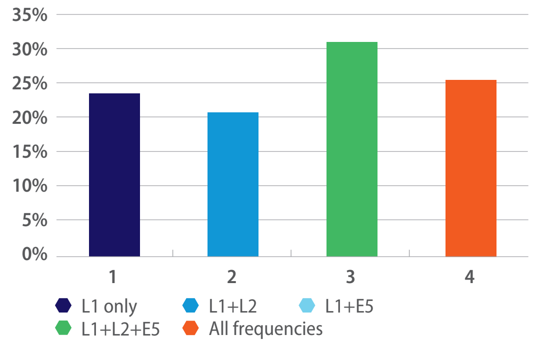
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



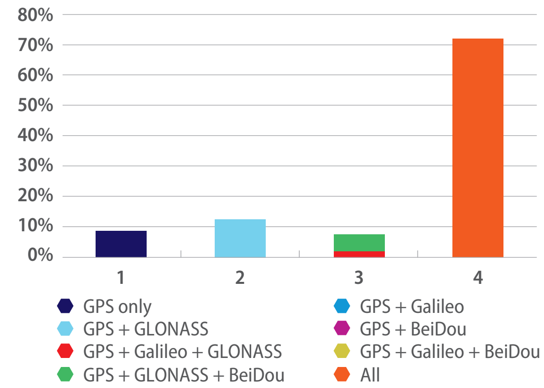
[2] shows the percentage of receivers capable of tracking each constellation

Supported frequencies by GNSS receivers[3]



[3] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 frequencies

Supported constellations by GNSS receivers[4]



[4] shows the percentage of receivers capable of tracking 1, 2, 3 or all 4 global constellations

Disclaimer: The charts above reflect publicly available claims from each manufacturer regarding product capabilities, and judgement on the domains to which they are applicable. Use in actual applications may vary due to issues such as certification, implementation in the end user product, and software/firmware configuration.

ENRICHED CHIPSETS PROVIDE CONTINUITY AND RELIABILITY IN COMPLEX ENVIRONMENTS

Typical state-of-the-art receiver specifications for high-accuracy macrosegment

Features	Geomatics	Agriculture
Form factor	Rugged smart antenna or modular unit with external antenna	Rugged smart antenna, remote control box
Channels	200-1100+	200-1100+
Typical observables	Dual-frequency carrier waves: all receivers Triple-frequency: most high-end models Quadruple: few high-end models CORS: Multi-frequency	Dual-frequency carrier waves: all receivers Triple-frequency: most high-end models Quadruple: few high-end models
Constellations	Multi-constellation	Multi-constellation
Receiver connectivity	Serial, USB, TCP/IP, Wi-Fi, Bluetooth, UHF/FH915 radio, 4G, Lemo, RTCM input/output CORS: + RJ45 Ethernet, Power over Ethernet, External oscillator, Dual-Power Input, PPS Output	Wi-Fi, Bluetooth, 4G, NMEA, RTCM input, Serial Lemo/DB9
User interface	Hardware buttons, web interface, external controller CORS: + Web interface, FTP services, email notifications	Hardware buttons, web interface, external controller
TTFF/TTC	RTK: < 10 s PPP: < 30 min worldwide (< 10 cm) < 5 min worldwide (< 50 cm) PPP-RTK: < 1 min	RTK: < 10 s PPP: < 30 min worldwide (< 10 cm) < 5 min worldwide (< 50 cm) PPP-RTK: < 1 min
Horizontal accuracy -95%	Static: 2.5 mm + 0.5 ppm RTK: 8 mm + 1 ppm PPP and PPP-RTK: < 5 cm DGNSS: 0.25 m + 1 ppm	- RTK: 8 mm + 1 ppm PPP and PPP-RTK: < 5 cm DGNSS: 0.25 m + 1 ppm
Vertical accuracy -95%	Static: 5 mm + 0.5 ppm RTK: 15 mm + 1 ppm PPP and PPP-RTK: < 10 cm DGNSS: 0.5 m + 1 ppm	- RTK: 15 mm + 1 ppm PPP and PPP-RTK: < 10 cm DGNSS: 0.5 m + 1 ppm
Sensors	E-bubble, tilt, compass IMU (high-end models)	E-bubble, tilt, compass IMU (high-end models)
Roll/Pitch accuracy of IMU (RMS)	Up to 0.01°	Up to 0.01°
Antenna	Wideband with multipath rejection CORS: Dorne-Margolin choke ring	Wideband with multipath rejection
Heading (2nd antenna)	High-end models in construction and mining	High-end models in precision agriculture
Heading accuracy	Ranges between 0.05-0.30°	Ranges between 0.05-0.30°
RTK&PPP readiness	All	Usually yes
PPP-RTK readiness	Few manufacturers, proprietary formats	Few manufacturers, proprietary formats

Disclaimer: The above specifications represent a typical GNSS receiver based on manufacturers' published literature for their latest products. Consequently discrepancies may exist between the installed receivers' characteristics and those stated above.

Compact sensor-enriched receivers provide reliable positioning in any environment

The modern high-accuracy GNSS receiver is a complex electronic device, capable of achieving millimetre-levels of accuracy using all available navigation signals in space. State-of-the-art modernizations include the increasing integration of affordable yet accurate IMU sensors, which yield reliable and continuous positioning in constrained environments. Many top manufacturers are developing positioning algorithms which focus on constellation-agnostic approaches for signal processing via digital correlation of all available navigation signals, regardless of satellite source. Innovative choke ring antenna designs with high-gain and multipath rejection are ensuring the quality of CORS network services.

Reduction in number and size of components decreases high-accuracy OEM form factor

Within the industry-standard high-accuracy OEM chipset (60x100 mm) there are currently many newly integrated sensors, and the number of GNSS channels exceeds 1100. The advancements in chipset design enable use of fewer components and lower power consumption, and many R&D companies are now producing compact (45x71 mm) and ultra-compact OEM boards (31x31 mm, e.g. Septentrio Mosaic-X5) without loss of accuracy. This is especially important for OEM board integration in high-accuracy drones, e.g. for mapping and agriculture. Sophisticated anti-jam and multipath mitigation techniques, and positioning rates up to 100 Hz are becoming a common commodity in GNSS receiver design.

The modern high-accuracy receiver features all capabilities

While in the past the receiver form factor was primarily designed based on its application mode (static, Differential GNSS, RTK or PPP), modern high-accuracy devices usually embed all those observation techniques into a single box. This provides flexible receiver customization by the end user, who may select from the variety of additional high-accuracy options and correction services available in the chipset. Thus a receiver may be configured either primarily for real-time operations, e.g. staking-out with centimetre accuracy or mapping/GIS with sub-meter accuracy, or as a static reference station. Additional options for receiver upgrades can be unlocked by obtaining codes provided by the manufacturer.

Notable exceptions from the smart antenna design are CORS receivers, as well as receivers dedicated for operations in harsh environments (e.g. machine control or marine surveying and engineering); these are still manufactured as separate GNSS signal processing units with external antenna. When GNSS-based heading is required, a typical case for marine surveying and machine guidance, usually two antennas are utilised.

ACCURACY 4.0 – THE NEW TECHNOLOGICAL TREND IN THE HIGH-ACCURACY SEGMENT

High-accuracy is empowered by the Fourth Industrial Revolution

Accuracy 4.0 is a newly-coined term describing the trend towards automation and data exchange within the high-accuracy GNSS segment. The main drivers include high-end receivers that are augmented with 4G connectivity and various sensors, backed with state-of-the-art data handling methods like cloud-processing and deep learning. In a world of supercomputing, intelligent robots, and autonomous vehicles, the high-accuracy segment is now fuses several technologies. The era of digitalisation and the integration of powerful GNSS-enabled technologies has had a sizable impact in every high-accuracy application. In this integration, inertial measurement units (IMUs) still play a key role.

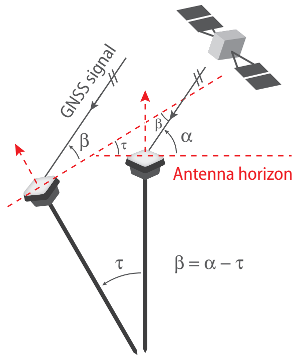
The evolution of GNSS/IMU integration - trends and sensor types

An IMU is a sensor that is sensitive to force and rotation due to the Earth's gravitational field and revolution. An IMU consists of three main parts; a triad gyroscope (the rotation rate sensor), a triad accelerometer (as the motion sensor), and a computer for movement calculation. The single integration of the gyroscope measurements provides information about the orientation of the sensor, while the double integration of the accelerometer measurements provides its position. In areas with challenging conditions for GNSS (e.g. cadastral measurements in urban canyons or agriculture in steep terrain), the GNSS/IMU integration gives rise to a reliable system that provides flexible centimetre-level static positioning, GNSS-based heading information, centimetre-level continuous mobile positioning, plus three-axis precision orientation.

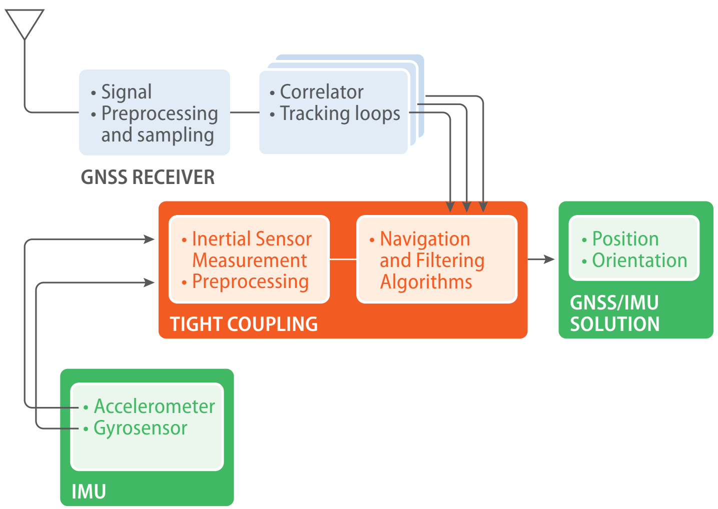
GNSS/IMU empower all high-accuracy segments

There are several areas making wide use of GNSS/IMU integration within the high-accuracy segment; receivers for geomatics, autonomous vehicles in agriculture, and mobile mapping systems (road, aerial or marine). While geomatics utilises this integration within a single smart antenna for its mobile field workflows, in agriculture the fusion is focused on autonomous navigation capabilities. In mobile mapping, the sensors are mounted on moving platforms (such as cars, marine vessels or airplanes).

High-quality products in this segment ensure that GNSS and IMU data is consistently time-synchronized to the mapping sensors (e.g. LiDAR, sonar, etc.) to enable precise georeferenced mapping. In geomatics, especially cadastral surveying and construction, this integration provides a significant reduction of trivial activities, such as site stakeouts and objects measurements. Compared to the e-bubble and tilt sensors, the IMU provides much more accurate vertical angle determination with better positioning results.



Generic processing workflow of GNSS/IMU integration



PPP-RTK SERVICES – AN INCREASINGLY ADOPTED HIGH-ACCURACY TREND

New services yet to be exploited in the high-accuracy segment

PPP-RTK is a solution that builds on the strengths of both RTK and PPP and promises to become a significant piece in the GNSS technological puzzle. It is an optimized variant of PPP which provides single receiver users with information that enables fast and reliable centimetre-level accuracy. The performance of PPP-RTK is empowered by an ionosphere model, whilst requiring a lower bandwidth to broadcast corrections than Network Real Time Kinematic (approx. 1500 bps, which is much less than the Virtual Reference Station (VRS), Flächen-Korrektur-Parameter (FKP) and Master Auxiliary Concept (MAC) protocols). A distinct characteristic of PPP-RTK is that it may combine data for orbital and clock corrections from a PPP network, while utilising data from a local RTK network to generate the ionospheric model. In addition, some of the data needed to model the ionospheric disturbances may be even provided by non-GNSS sources.

Similar to PPP, PPP-RTK utilises the Space-State Representation (SSR) approach for the parametrisation of the measurement errors. SSR provides users with individual corrections for all GNSS error sources (clocks, orbits, biases, etc.) at an optimal update rate, allowing the user to reconstruct the compound error whilst optimising the required bandwidth. On the contrary, the observation-state approach (OSR), which is typically used in RTK, provides the user directly with a single combined correction for all error sources. Both approaches are utilised for real-time data transmission via either open or proprietary protocols.

Both OSR (for RTK) and SSR (for PPP) corrections are supported in the standard Radio Technical Commission for Maritime Services (RTCM) protocol, either for a single reference station or network (NTRIP). PPP-RTK implementation within the RTCM however is still missing. As a result there has been a strong push from users in recent years for standardisation of PPP-RTK corrections via new messages within the RTCM protocol.

A detailed comparison of the features of PPP-RTK compared to the rest of the real-time methods is given in the table below.

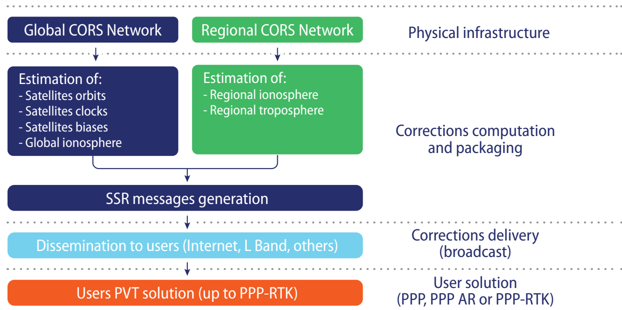
	OSR (Observation State Representation)		SSR (Space State Representation)		
	RTK	Network RTK	Carrier PPP	Code PPP	PPP-RTK
Error mitigation	Combined range correction		Orbits, clocks, biases		Orbits, clocks, biases, iono, tropo
Accuracy	~ cm		< dm	~ 3 dm	< cm
Time required	< 5 s		~ 20 min	< 1 s	< 5 s – 100 s (1)
Service area	local	regional	global	global/ regional	global/ regional
Single frequency capability	✓ receiver dependent		✓ receiver dependent	✓	✓ (2)
Required bandwidth	medium	medium-high	low	low	low-medium

(1) depends on update rate
(2) depends on the algorithm used

Benefits of PPP-RTK over standalone PPP and RTK

Several innovative, optimized PPP-RTK algorithms are currently being investigated by GNSS service providers, most of which focus on un-differenced observations rather than double-differenced ones with the ultimate goal - to achieve a higher independence from the density and coverage of the local Network Real Time Kinematic (NRTK) infrastructure. The OSR approach is typically implemented by NRTK operators through bidirectional links between the user and the server, which commonly limits the numbers of network connections and the stability of the system. On the other hand PPP-RTK is based on a unidirectional link, which combined with the optimized update rate of the various error sources enables broadcast of precise corrections at lesser bandwidth, with fast convergence time and unlimited number of user connections. Also, unlike GNSS augmentation service providers that require separate user subscriptions for NRTK (preferred in areas with good reference station coverage) and PPP (used mainly in areas without such), PPP-RTK makes use of a single user account, thus enabling a complete environment-independent service. Despite the positive expectations, some applications that require nearly instantaneous initialisation may find PPP-RTK still lacking the speed of TTFF of traditional RTK and network RTK methods. Also, PPP-RTK still relies on data from RTK networks, albeit with lesser density, hence it may become unavailable with increased distance from network coverage, e.g. at sea.

Generic PPP-RTK service provision scheme



PPP-RTK services as of mid-2020

Several service providers are already offering different variations of PPP-RTK, e.g. Trimble RTX Fast or TERIA PPP–RTK. In parallel, national or regional public efforts to provide PPP-RTK services are also fully underway. In Japan for instance, QZSS's Centimeter Level Augmentation Service (CLAS) - a satellite-based open PPP-RTK correction service – has been operational since November 2018. Many testbeds are also in place including in South Korea, Australia, Germany and Denmark.

On the commercial side, Fugro's Marinestar G4+ is one of the prominent services for marine surveying and engineering. On land, the SAPA services – released in early 2020 by Sapcorda Services GmbH – are PPP-RTK services that can be used throughout most of Europe and the USA.

GNSS FUSION FOR FULLY-CONNECTED AUTOMATED WORKFLOW MANAGEMENT

Cutting-edge GNSS-enabled applications require multi-instrumental approach

Several high-accuracy segments embed GNSS as the core technology for achieving fully-automated workflows. Depending on the exact application, automation relies on interconnectivity and the incorporation of sensors, robots and powerful data analytics – e.g. GNSS, cameras (monocular, stereo, RGB with pixel depth, visual Simultaneous Location And Mapping or 'SLAM'), LiDAR, IMUs, sonar, odometers, bathometers, and others.

Mobile Mapping Systems (MMS) utilise a pair of high-accuracy RTK GNSS receivers to georeference in real time LiDAR-derived point cloud datasets and maintain a stable heading angle. Professional mapping drones adopt ultra-compact Post-Processing Kinematic (PPK)-enabled OEM boards to reduce the reliance on real-time corrections via the Internet, as well as the necessity to establish Ground Control Points (GCPs). In the architectural, engineering, and construction industries, all fully-connected GNSS operations at the construction site provide real-time data to the Building Information Models, thus enabling higher data integrity, increased productivity, and faster decision making.

For hydrographic mapping of lakes, dams or mine tailings, precise RTK GNSS receivers are coupled with shallow single- or multi-beam sonar. Construction site elements may be visualized in situ with the aid of GNSS-enabled devices for mixed reality. Indoor mapping relies on the emerging technology SLAM, which may be coupled with precise GNSS to ensure seamless transition from the outdoor positioning mode. All these are examples that highlight the continuous fusion trend in high-accuracy.

Autonomous tractors equipped with multiple sensors drive agriculture into the future

The fusion of data collected by different sensors is a key component in the implementation of precision agriculture. Its most widespread application is in the execution of variable rate application of inputs, whereby farmers use prescription maps developed using optical or radar satellites, upload them onto the onboard unit of agricultural machinery (using ISOBUS) and then perform site-specific management at even 2.5 centimetre level of relative accuracy. The tractors are also equipped with mechanical and vision sensors (optical, multi-spectral, hyperspectral cameras and even LiDAR), the readings of which are combined in real-time with GNSS signals.

This paradigm has proliferated thanks to Artificial Intelligence (AI) which has enabled the automated extraction and analysis of different data streams (e.g. geolocalised changes in field, soil, and other agronomy-relevant properties and even weather/climate information). AI has also enabled the implementation of deep learning methodologies, extensively used for fully autonomous robots performing tedious agricultural activities such as weeding or spraying. In such cases, robots combine SLAM (achieved via IMUs and LiDAR) with GNSS to navigate the fields, use different types of cameras and machine vision techniques to distinguish between plants, or between plants and weeds, and perform the necessary interventions. Such approaches strongly rely on multi-constellation and multi-frequency solutions supported by RTK, PPP or PPP-RTK corrections.

CORS NETWORKS ARE THE BACKBONE OF HIGH-ACCURACY POSITIONING

CORS networks are the modern realisation of geodetic coordinate systems

High-accuracy applications rely strongly on GNSS correction data from external sources. Serving as the paramount provider of GNSS correction data, worldwide Continuously Operating Reference Station (CORS) networks enable most of the terrestrial sub-metre positioning services. Two major types of CORS networks exist today: non-profit and commercial.

The International GNSS service (IGS) operates the largest non-profit CORS network in the world: a complex system of 500+ reference stations, maintained by 200+ voluntary organisations (universities, self-funding agencies and research institutions). It is the main source of products that enabled the development and testing of the PPP method, such as real-time precise satellite orbit and clock data.

GNSS data from IGS stations are used for periodical realisations of the International Terrestrial Reference System (ITRS), which are produced by the IERS (International Earth Rotation Service) under the name International Terrestrial Reference Frames (ITRF). The IERS processing centre integrates GNSS with other sophisticated data sources (VLBI, SLR and DORIS). The resultant reference frame is the basis to which all GNSS synchronise their own geodetic reference systems. For example WGS84, the reference system of GPS, performs secular updates of its coordinates with respect to ITRF. As a result the last realizations of WGS84 (update G1674) are coincident with ITRF2014 at the centimetre level. Like GPS, Galileo established a dedicated terrestrial reference frame (GTRF) as an independent realization of the ITRS based on the estimated coordinates for each of the Galileo Sensor Station sites. According to Galileo requirements the three-dimensional differences of the position compared to the most recent ITRF should not exceed 3 centimetres (2-sigma).

Currently IERS undergoes a project to provide the new ITRF2020 solution, which is planned to be released by late 2021.

Commercial CORS form the frontline of GNSS correction services

In general, commercial CORS networks provide two types of services: Network RTK through dense station distribution with national/regional coverage (approx. 1 station in every 70 kilometres) and high availability of correction streams, or PPP from less dense networks (1 station in several hundred kilometres) with worldwide coverage. Both are mainly exploited in real time, with corrections broadcasted either though the Internet (NRTK and PPP) or via dedicated L-band satellite link (PPP mostly). Like their non-profit analogue, commercial CORS utilize dedicated GNSS receivers, frequently complemented with external clock oscillators, data processing centres and real-time dissemination of GNSS products. Commercial CORS networks are also providing precise local ionospheric models to their clients, which are especially important in the recent uptake of the PPP-RTK and single-frequency PPP users. Without ionospheric models these users cannot eliminate the inherent ionospheric delay of the GNSS signal. Due to their low-cost, sub-metre accuracy, and large number of possible users, single-frequency services became subject of renowned interest in the recent years.

Several RTK networks have started to distribute the new PPP-RTK products, which may provide a powerful driver for technological advancement within the high-accuracy segment. To acquire absolute coordinate accuracy in the segment, especially in geomatics applications like cadastral surveying, all GNSS coordinates acquired from the array of RTK networks need to strictly comply with the adopted national geodetic reference frames and the relevant transformation parameters to the ITRF. A good example for that are the PPP services, which are provided mostly in the ITRF reference frame, and for critical high-accuracy applications (e.g. deformation monitoring) need to be transformed to the legal reference system. Approaches such as GNSS levelling may ensure that these transformations can be also applied in vertical reference frames with respect to the geoid and other gravity-based models of the Earth.

High-accuracy antenna calibrations in the IGS frame

Apart from IERS, the IGS maintains a parallel GNSS-only derived reference frame, the current realisation being named IGS14. For most practical uses ITRF2014 and IGS14 are identical. IGS14 is currently adopted as the precise coordinate frame for satellite and receiver antenna calibrations. Two types of antenna calibration are available: the state-of-the-art absolute, and its predecessor - the relative.

Absolute calibrations are routinely computed by several institutions implementing different methods: field calibrations (picture on the right) vs. anechoic chamber calibrations. Despite the methodological differences, these methods show very close agreement.

The Multi-GNSS Experiment and Pilot Project (MGEX)

The IGS MGEX had evolved from an experimental stage to being declared ‘pilot project’ in 2016. It provides tracking, collation and analyses of all available GNSS signals – GPS, GLONASS, Galileo, BeiDou, QZSS, and NavIC. MGEX CORS stations (numbering 313 in early 2020) are capable of multi-frequency multi-constellation data acquisition. They are providing data which expanded IGS’s products portfolio with precise ephemeris data and bias information for all constellations. Many of these products are available in near real-time and are utilized in a number of different PPP services.

Global map of the IGS MGEX stations, together with details of GNSS receivers used and precise products is available at: *igs.org/network?network=multi-GNSS*.

HIGH-END GNSS SCIENTIFIC APPLICATIONS REQUIRE ULTIMATE ACCURACY LEVELS

High-accuracy GNSS empowers weather forecasting and climate change research

The uptake of GNSS constellations has proved instrumental for high-end research endeavours that are vital for everyone on Earth. Complex analyses, combining space geodetic techniques, CORS stations' data and climate research provide many new products that would be unattainable without the application of high-accuracy GNSS.

Remote sensing of the atmospheric water vapour with GNSS is an established technique, known as **GNSS Meteorology**. It is being used by high-end scientific applications for around a decade and has a dedicated Working Group within IGS. Data from IGS and other CORS networks are used for operational positioning and monitoring of data time series. By mapping the distribution of gases within cross-sections of the troposphere (a technique similar to medical tomography, but using GNSS signals instead), it provides reliable information on water vapour's spatio-temporal variability. The total tropospheric delay of the GNSS signal is usually expressed in zenith direction, hence it is called zenith total delay (ZTD). Its conversion into Integrated Water Vapour (IWV) has become routine in GNSS data processing. GNSS meteorology supports many Numerical Weather Prediction (NWP) services on a global scale either as a primary tool, or as a complementary method to classical weather atmospheric sounding techniques. One such service is the GNSS Water Vapour Programme of the Network of European Meteorological Services (EUMETNET E-GVAP, egvap.dmi.dk). Consecutively, these models may be used to improve the positioning accuracy of PPP. Recently, Galileo has also entered this scientific domain through the high quality of the tropospheric estimation achievable by processing its signals.

Another prominent approach for atmospheric studies, developed by high-accuracy GNSS users in the scientific sector, is the **GNSS Radio Occultation** (GNSS-RO) technique. This technique was developed by a group at NASA's Jet Propulsion Laboratory and over the years has demonstrated unmatched impact on weather forecasts. It uses GNSS measurements received by a low-Earth orbiting satellites to profile the Earth's atmosphere and ionosphere with high vertical resolution and global coverage. The high accuracy and vertical resolution of GNSS-RO data make them ideally suited to study weather forecasting and atmospheric processes, climate monitoring and model verification, and space weather and ionospheric research. Some notable satellite missions that incorporate GNSS-RO research are the German mission CHAMP, the US-German mission GRACE, and the US-Taiwan FORMOSAT/COSMIC mission.

While most of the GNSS-RO investigations are strictly confined to the research and weather forecasting sectors, there are several companies that provide commercial services to scientific, government and other high-level end customers. For example, GeoOptics (geooptics.com) provides Radio Occultation services through its own dedicated constellation of nanosatellites, named CICERO. Another company, Spire, which currently operates 80 satellites in orbit, aims to leverage Radio Occultation technology to assimilate atmospheric density information into its own weather model runs, providing accurate forecast to the Weather industry (*spire.com/weather/*).

BalkanMed Real Time Severe Weather Service

Interreg Balkan-Mediterranean BeRTISS

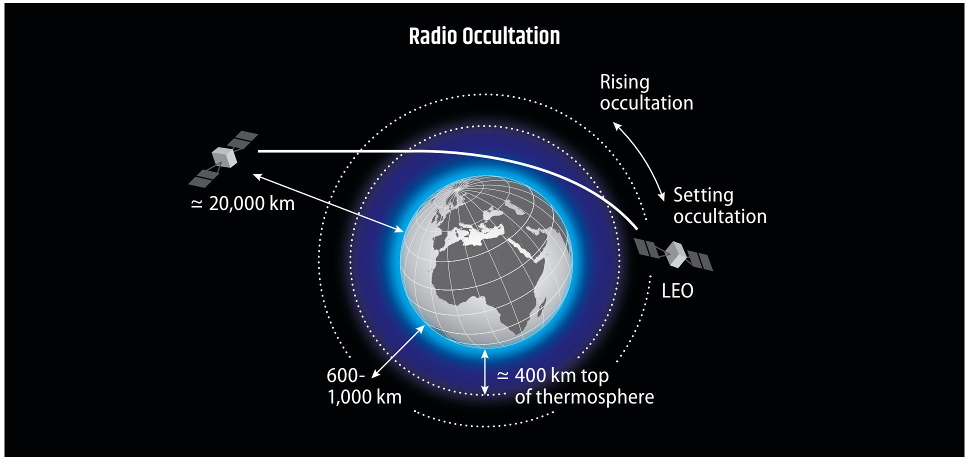
(BeRTISS) project is developing a pilot transnational severe weather service exploiting GNSS products to enhance the safety, quality of life and environmental protection in the Balkan-Mediterranean region (Bulgaria, Cyprus and Greece). The project aims to provide timely information and warning regarding severe weather events as well as long-term monitoring of weather and climate change in the region, through the mapping and visualization of water vapour via GNSS meteorology techniques. The EU-funded BeRTISS project is a bridge between the geodetic community, the GNSS remotely sensed data providers, the atmospheric community, and the data users.

More information at: bertiss.eu

The COSMIC-2 GNSS-RO mission

This mission utilises six satellites launched successfully on June 25th 2019 into low-inclination orbits. It is jointly operated by U.S. institutions (National Oceanic and Atmospheric Administration (NOAA), Air Force (USAF), University Corporation for Atmospheric Research (UCAR)) and Taiwan's National Space Organization. The GNSS-RO payload, named TGRS (Tri-GNSS Radio-occultation System), was developed by NASA's Jet Propulsion Laboratory and will be capable of tracking more than 4,000 high-quality profiles per day (across the 6 satellite constellations). The COSMIC-2 is a successor of the pioneering mission COSMIC-1 and will provide a revolutionary increase in the number of atmospheric and ionospheric observations, which will greatly benefit the research and operational communities.

Data products are available at: cosmic.ucar.edu



HIGH-ACCURACY IS EXPANDING ITS HORIZONS WITH HELP FROM MASS-MARKET DEVICES

High-volume meets high-accuracy: an exciting two-way exchange

The interaction between the high-accuracy and the high-volume segments is driven by the convergence of two trends: high-accuracy equipment becoming cheaper by losing some of its advanced features, whereas consumer grade equipment gets more capable and thus may become a possible alternative. In the latter case low-cost equipment reaches higher-grade performance level when equipped with extra inertial modules, rugged enclosure, appropriate antenna and, when RTK is needed, radio packs. At the same time, some of the most advanced smartphones have been shown to achieve (in rural environments) sub-metre accuracy, or even centimetre if post-processed using a professional-grade antenna and suitable augmentation data. To achieve sub-metre accuracy, they are equipped with dual-frequency receivers (typically L1/E1-L5/E5a) and benefit from the wide-band signals that provide greater resilience to multipath effects. The desired positioning accuracy is achieved thanks to access to GNSS raw phase measurements (via APIs) and the fusion of GNSS with integrated inertial sensors and additional terrestrial based signals (4G/5G, WiFi, NFC, Bluetooth, UWB). Nonetheless, significant challenges remain in relation to the performance of the integrated antennas.

Whilst smartphones start to achieve high-accuracy (see also High-volume and transport devices segments in previous chapters), the high-accuracy sector itself is looking more into smartphone-based execution of certain operations. One of the most prominent is related to data collection. In that regard, the 'Bring your own device' (BYOD) trend is emerging, whereby surveyors and mappers use their own smartphones as an alternative to the proprietary data collection devices. In practice, manufacturers are creating a user-friendly interface by pairing iOS and Android developers to their own hardware and firmware. In this paradigm, many of the leading manufacturers are providing dedicated Apps to their high-accuracy users allowing them to benefit from the best of two worlds: familiar user interfaces and sophisticated data collection capabilities.

Accessing high-accuracy with smartphones

The release of the Android Raw GNSS Measurements API – which is compatible with Android 7.0 (Nougat) and higher, brought a revolution in the use of smartphones for the performance of GNSS-based operations, some of which enter the lower realm of high-accuracy. In practice, the ability to access not only the Position Velocity Time (PVT) solution but also the raw GNSS measurements, allows developers to reconstruct pseudorange, carrier-phase, Doppler and signal-to-noise ratio (SNR) observables and access decoded navigation messages.

In order to support the proliferation of applications using smartphones, GSA launched the GNSS Raw Measurements Task Force (see page 37 for more) in 2017 and has been fostering progress ever since. Today, with multiple dual-frequency smartphones in the market, the exploitation of this opportunity is on the rise. As new algorithms are being developed and smart solutions regarding the antennas are being proposed, more cases of smartphone-based high-accuracy operations are documented. This effect is not only confined in Mass-market applications but starts to spill over in traditional geomatic domains such as geosciences (e.g. for displacement analyses or ionospheric observations). This trend is expected to grow as dedicated tools (such as the GNSS Compare mobile application) become available.

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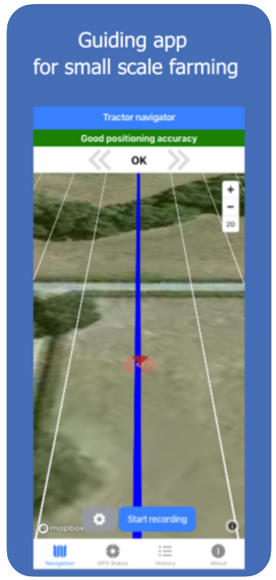
Proliferation of Smartphone Tools in Agriculture

There are tens of mobile farming tools on the App stores: from the applications that help with the soil sampling, through tools that record everything that happens on the farm and geo-tagging photos that support the digitisation of CAP, to machinery guidance mobile apps that benefit from Galileo dual-frequency or open and free access to Sentinel data.

One of the examples is the Tractor Navigator app that got the second prize in GSA's MyGalileoApp contest: an intuitive tool providing guidance to farmers during their work, with enough accuracy for most small farms use cases. With no external device required, farmers can set up the app for all their machines and use real-time guiding information in the field while keeping costs on the effective level.



AGRICULTURE USERS KEEP BENEFITTING FROM E-GNSS AND COPERNICUS SYNERGIES

Agriculture: where Copernicus' unique technical features meet higher accuracy enabled by Galileo

Site-specific farm management systems have been helping farmers to optimise their agriculture production and minimise their inputs whilst also protecting the environment. Knowing what is happening where and when relies on continuous monitoring of the fields; for that, the help of Earth Observation satellites such as the Copernicus Sentinels has proven to be ground-breaking. For example, Sentinel 2 provides a 10-metre resolution that can be relevant even to individual land parcels, whilst its revisit time stands at 5 days making it highly relevant for crop dynamics monitoring. By measuring the energy reflected in visible and infra-red bands, Sentinel 2 enables the calculation of Normalized Difference Vegetation Index (NDVI). The Sentinel-1 Synthetic Aperture Radar (SAR) mission enables remote sensing regardless of the weather conditions (i.e. cloud masking). Finally, the optical instruments of Sentinel 3 may also contribute to large-scale vegetation and crop condition mapping.

With rich time-series and accurate prescription maps in hand, farmers are able to plan their agricultural inputs (e.g. fertiliser, seed, pesticide) more efficiently. For this to work, the use of ISOBUS (i.e. the protocol that manages the communication between tractors, software and equipment) is critical. It allows to load prescription maps onto the terminal, which in turn ensures that the appropriate application rates for the specific input are defined for the given GNSS coordinates. This process strongly benefits from the higher accuracy enabled by E-GNSS services.

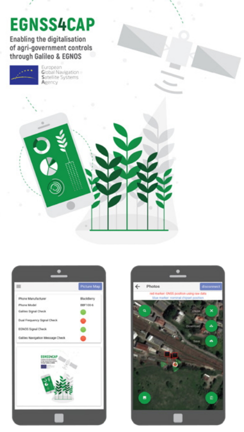
Looking into the near future, additional synergies can be exploited. Notable among them is soil moisture monitoring, where GNSS-Reflectometry and Sentinel-1 SAR measurements show strong promise. Projects such as H2020 Mistrale and multiple start-ups and SMEs are exploring technological opportunities in that regard.

European Space Programmes for the Common Agricultural Policy

Another important area of synergy arises in the case of checks for area-based EU Common Agricultural Policy (CAP) payments. The enhanced monitoring approach uses the Earth Observation data provided by the Copernicus Sentinels and other Earth Observation satellites, complemented when needed by geo-tagged photos. The latter, taken with smartphones by the farmers themselves, benefit from the increased accuracy and the upcoming authentication signal of Galileo Open Service. This effort is greatly aided by the recently launched E-GNSS4CAP application.

The **E-GNSS4CAP** application will help farmers to capture geo-tagged photos as an extra layer of evidence that both supports and complements the Copernicus Sentinel-based monitoring approach for the implementation of CAP. Made available as an open source, free mobile phone application for Android, E-GNSS4CAP makes use of Galileo differentiators (accuracy and authentication) to provide location and timing of photos of the agricultural fields, thus supporting the efficient reporting to Paying Agencies. Ultimately, this will help to reduce the number of On The Spot Checks (OTSC) and ensure a fair, modern and accurate implementation of the Common Agricultural Policy.

More information at: https://www.egnss4cap.eu/



RTK positioning and navigation for autonomous agriculture vehicles

eFarmer B.V. is a developer and manufacturer of FieldBee(™) product line for high-accuracy navigation using smartphones and tablets. FieldBee GNSS receivers combine RTK positioning algorithms with modern IoT-technologies for flexible usage and integration with automotive systems. This enables more affordable robotization for autonomous vehicles and precise operations. Such solutions can be used both on new and old machines. FieldBee(™) GNSS receiver combines multi-constellation types with several communication channels, which are commonly used in IoT devices. The device is configured over Bluetooth or WiFi using open REST-protocol. The correction signal is received either from NTRIP-provider over the Internet or from the reference station over the radio channel directly.

FieldBee(™) Tractor Auto Guidance system provides centimetre accuracy for the automation of fieldwork operations. It uses optimised elevation mask with less than 15 degrees that achieves better RTK performance. RTK 10 Hz positioning update rate provides sensitive navigation with operation speed 3.15km/h. The combination of RTK receiver and IMU-sensors compensates terrain during navigation.

FieldBee(™) GNSS communication NMEA 0183, NMEA 2000, CANOpen protocols allow for the fast implementation of RTK in autonomous vehicles. The goal of eFarmer B.V. is to make all agriculture machines autonomous, smart and precise.

More information at: fieldbee.com and efarmer.nl.

Testimonial provided by the company

E-GNSS SUPPORTS THE FULL RANGE OF HIGH-ACCURACY APPLICATIONS AND OPENS NEW POSSIBILITIES FOR INNOVATIVE SOLUTIONS

Galileo is a pillar of multi-frequency/multi-constellation solutions for high-accuracy

With 22 active satellites in orbit, Galileo has enabled the full range of benefits associated with multi-constellation and multi-frequency receivers. Thanks to Galileo, high-accuracy users enjoy greater service availability, faster times to first accurate fix and greater resilience to multipath and interference effects. RTK providers have already upgraded their networks to be Galileo-ready, and PPP as well as PPP-RTK providers follow suit. This effectively means that Galileo enables or contributes to the desired accuracy, continuity, reliability and overall performance of high-accuracy operations in any environment, including remote or challenging areas. This applies to virtually all high-accuracy applications from agriculture, to land and marine surveying and from mining to construction and mapping.

Galileo High-Accuracy, OS-NMA and Commercial Authentication Services open up fresh possibilities for high-accuracy users

By transmitting PPP corrections through the Galileo E6 signal data component (E6-B) and by terrestrial means (internet), the High Accuracy Service (HAS) will enable positioning horizontal accuracy of under 20 centimetres in nominal conditions. Moreover, by empowering triple-frequency receivers or disseminating atmospheric corrections for Europe, it will lead to faster convergence times. At the same time, the Open Service Navigation Message Authentication (OS-NMA), and the Commercial Authentication Service (CAS) will assure that the positioning is based on authentic measurements and data transmitted by Galileo satellites. This is because these services provide access to encrypted codes on the E6 signal pilot component (E6-C). This has a profound impact for high-accuracy users that need to increase the robustness against spoofing and meaconing.

GISCAD-OV

GISCAD-OV project is developing and validating an innovative service that relies on Galileo HAS and Precise Point Positioning-Ambiguity Resolution (PPP-AR) quick convergence techniques. This service will be supported by the GISCAD-OV Service Operator Centre, able to fully integrate the existing Augmentation and National infrastructures for improving Cadastral operations efficiency and effectiveness, reducing Cadastral procedures' time for the benefit of the citizen. By exploiting the E-GNSS added value, this Horizon 2020 project will serve the whole value chain in the cadastral domain.

More information at: giscad-ov.eu

GALIRUMI

GALIRUMI project is building a robot for herbicide-free weed control in dairy farming. Robotic weeding will reduce the environmental impact of dairy farming by eliminating herbicide use and reducing exposure of farm workers to herbicides. It will also remove an important obstacle for dairy farmers to switch to organic production, thereby contributing to an increase in production of organically produced milk and higher incomes for farmers.

GALIRUMI will develop and demonstrate a number of innovative technologies in weed detection, weed degradation, autonomous vehicles and robot-as-a-service for precision dairy farming based on precise navigation provided by E-GNSS.

More information at: galirumi-project.eu

E-GNSS contribution to Key Performance Parameters

Key Performance Parameter (KPP)*	EGNOS contribution	Galileo contribution
Accuracy	⬢⬢⬡	⬢⬢⬡
Availability		⬢⬢⬢
Continuity		⬢⬢⬢
Integrity	⬢⬢⬢	
Robustness	⬢⬢⬢	⬢⬢⬢
Time To First Accurate Fix (TTFAF)		⬢⬢⬡

⬢⬢⬢ Major contribution, capable of enabling new GNSS applications
⬢⬢⬡ Medium contribution, enhancing the user's experience
⬢⬡⬡ Low contribution, performances improved but no major difference at users' level

* The Key Performance Parameters are defined in Annex 3

TIMING DEVICES

ACCURATE, RELIABLE AND ROBUST: THE DEMANDING REALITY OF TIMING DEVICES

Characterisation of timing and synchronisation solutions

Technologies and solutions presented in this chapter have been developed for the following Timing and Synchronisation (T&S) applications:

- **Telecommunications:** network management and synchronisation between base stations;
- **Energy:** to obtain exact and cyclic measurements of network status in order to monitor for possible failures and to intervene in a timely manner;
- **Financial:** for institutions to timestamp financial transactions and to ensure their correct execution;
- **Transport:** for safety-related applications, such as air traffic management or autonomous vehicles.

The telecom industry represents the largest user group, and ambitious plans for 5G technologies will require better synchronisation accuracy than ever before. New regulatory frameworks require financial operators to synchronise their computer systems, while energy networks will become more efficient through better synchronisation.

A common driver for all these applications is the need for stable accuracy and improved robustness and resilience. Significant research and development efforts have therefore been made at various levels of the timing processing chain to meet this demand. In particular multi-constellation and multi-frequency adoption, but also innovative Time-Receiver Autonomous Integrity Monitoring (T-RAIM) and interference monitoring algorithms aim to respond to this demand for improved accuracy, increased resilience, and improved availability.

This chapter also explores the role of GNSS in both digital networks (e.g. digital cellular networks, wide area networks, local area networks) and analogue networks (e.g. radio access networks, power distribution, fixed-line analogue telephone) architectures. It describes the main standards for the relay of precise, synchronised time over a network and presents E-GNSS added-value in the overall T&S landscape, with both Galileo Open Service Navigation Message Authentication (OS-NMA) and Galileo advanced timing functions.

Key performance parameters for timing and synchronisation

Synchronising network clocks requires the use of at least one reference clock, which can be sourced either in-house or externally. Three types of synchronisation can be distinguished; frequency synchronisation, phase synchronisation, and time synchronisation. These are further described on page 80.

Most contemporary time synchronisation solutions require the use of a traceable time source so that events across different locations can be correlated. In order to guarantee traceability, the time reference source origin must be known so that the measurement results can be related to a time standard (e.g. International Atomic Time [IAT] or Coordinated Universal Time [UTC]) through a documented unbroken chain of calibrations.

With the advent of 5G and autonomous vehicles, the need for improved synchronisation accuracy*, continuity, and availability is increasing. Besides timing accuracy, continuity, and availability, the most important parameters for timing solutions are integrity and robustness, in order to increase protection and resilience of the overall system against GNSS system faults, jamming or spoofing.

Timing key performance parameters

Key Performance Parameter (KPP)*	Timing Devices
Accuracy	High priority
Availability	High priority
Continuity	High priority
Indoor penetration	Low priority
Integrity	High priority
Latency	Low priority
Power consumption	Low priority
Robustness	High priority
Time-To-First-Fix (TTFF)	Medium priority
Traceability	High priority

High priority · Medium priority · Low priority

* Accuracy refers to time, phase and frequency accuracy:
Frequency accuracy refers to the difference in frequency between the reference clock and the recovered client clock over a time interval, expressed in parts-per quantity (e.g. parts per million (ppm), parts-per billion (ppb)).
Time/phase accuracy refers to the time/phase offset between reference clock and recovered client clock, expressed in seconds.

** The Key Performance Parameters are defined in Annex 3.

THE GNSS TIMING INDUSTRY IS STABLE AND MATURE, BUT ALL PLAYERS DIFFERENTIATE THEIR OFFER BY MARKET SEGMENT AND FUNCTIONALITIES

Leading component manufacturers

BRANDYWINE COMMUNICATIONS	North America	*brandywinecomm.com*
ELPROM	Europe	*elpromatime.com*
FREQUENCY ELECTRONICS	Asia-Pacific	*freqelec.com*
FURUNO	Europe	*furuno.com*
GORGY TIMING	Europe	*gorgy-timing.co.uk*
JACKSON LABS	North America	*jackson-labs.com*
MEINBERG	Europe	*meinbergglobal.com*
MICROCHIP	North America	*microchip.com*
MICROSEMI	North America	*microseni.com*
OROLIA (SPECTRACOM)	Europe	*orolia.com*
OSCILLOQUARTZ	Europe	*oscilloquartz.com*
SEIKO SOLUTIONS	Asia-Pacific	*seiko-sol.co.jp*
SEPTENTRIO	Europe	*septentrio.com*
SEVEN SOLUTIONS	Europe	*sevensols.com*
TRIMBLE	North America	*trimble.com*
U-BLOX	Europe	*u-blox.com*

Key players in timing and synchronisation

For decades GNSS has provided significant benefits to T&S user communities by delivering a free and highly accurate time and synchronisation capability, available worldwide that is traceable to an international time scale (UTC). GNSS has been rapidly adopted by T&S user communities with a strong impetus from the telecoms industry, which still represents the largest user base. The telecom sector's needs and standards therefore have strongly influenced the corresponding developments and led to innovations that benefit other domains. Moreover, despite the maturity of GNSS integration in T&S, the T&S industry is still very active with a view to overcoming many challenges ahead. This is linked to an increased need for reliability and security, supported by an evolution of regulation, and ever increasing user requirements in terms of accuracy, stability, and reliability. With the advent of 5G, challenges linked to network calibration are becoming increasingly important. Technology developments will be driven by the need to expand services without multiplying the networks (e.g. through the use of 'small cells'), as well as the global demand for broadband communication and new applications enabled by future mobile infrastructures (e.g. V2X, smart city, robots, UAVs or autonomous vehicles).

The T&S value chain is primarily composed of GNSS chipset producers, who are usually general-purpose module manufacturers and GNSS time product manufacturers, who then develop timing products, either as Original Equipment Manufacturer (OEM) boards or as packaged systems. System integrators then design, deploy and maintain GNSS T&S equipment in complex networks, whose operators are the end users of the equipment. Calibration services or consultancy and maintenance can also be provided by equipment resellers.

Most companies presented in the table usually specialize in a specific market sector subset such as telecoms, energy, finance, transport, automation or military, which are served by more than two hundred different products. They have started to develop solutions for improving robustness against jamming/spoofing in their product roadmap. This includes in-house development and technological partnership on specific components (e.g. smart antennas). Some companies also acquired specific technologies via Mergers and Acquisitions.

IMPROVED ROBUSTNESS TO GNSS THREATS AND AVAILABILITY ARE BEHIND THE GROWING ADOPTION OF MULTI-CONSTELLATION AND MULTI-FREQUENCY TIMING RECEIVERS

Multi-constellation adoption

GPS L1 remains the standard configuration for timing receivers in 2020. While all chips used in T&S applications are Galileo-enabled, more than 40% of GNSS T&S products in use are Galileo-enabled.

Multi-constellation adoption responds to the demand for increased resilience and improved availability (especially in attenuated environments, urban canyons, or rural areas). Some operators however still remain reluctant to adopt multi-constellation solutions because of a lack of awareness of the issues that it may solve, and because of potential inconsistencies with legacy equipment in their network that are unable to track multiple constellations.

Thus, today 50% of timing receivers are capable of processing at least two constellations. Among the multi-constellation receivers, the vast majority (over 60%) are able to process four constellations. Few professional applications are capable of processing only three constellations (around 20% of the multi-constellation receivers).

The highest penetration for Galileo is in Europe, followed by Asia-Pacific (similar to GLONASS). BeiDou and Galileo have a similar penetration in Europe.

Multi-frequency adoption

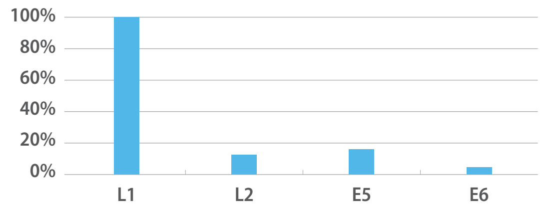
A limited share (13%) of GNSS time products now offers multi-frequency, with L1 + L2 the dominant frequency pairing of choice, followed by utilisation of all frequencies. The L1 + L2 share is expected to reduce in favour of L1 + E5 products, or even triple-frequency L1 + L2 + E5 capability.

Multi-frequency solutions are currently only integrated in high-end solutions to improve accuracy and increase robustness. Penetration of dual-frequency and triple-frequency receivers therefore remains low, although a growth is expected in the next five years.

Dual-frequency solutions are only deployed in North America and Europe, as one of the responses to the increased demand for improved critical infrastructure robustness.

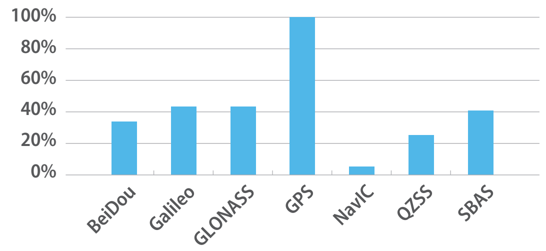
Disclaimer: The charts above reflect publicly available claims made by manufacturers regarding their product capabilities, and judgement on the domains to which they are applicable. Use in actual applications may vary due to issues such as certification, implementation in the end user product, and software/firmware configuration.

Frequency capability of GNSS receivers[1]



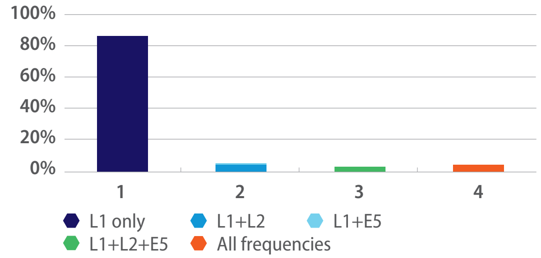
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



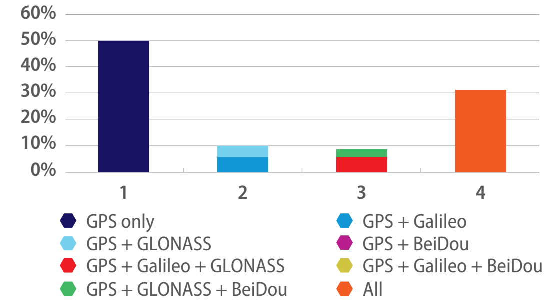
[2] shows the percentage of receivers capable of tracking each constellation

Supported frequencies by GNSS receivers[3]



[3] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 frequencies

Supported constellations by GNSS receivers[4]



[4] shows the percentage of receivers capable of tracking 1, 2, 3 or all the 4 global constellations

Towards strong adoption of GNSS resilience features

T&S receiver manufacturers have demonstrated strong interest in the implementation of GNSS resilience features against signal disruption and corruption, and this interest is expected to grow over the next five years. Multi-constellation and multi-frequency features remain the favoured approach for increasing T&S receiver robustness, however anti-interference monitoring algorithms are now offered by 10% of T&S products, followed by anti-spoofing monitoring algorithms at 8%.

T-RAIM integrity monitoring algorithms are gaining wider levels of adoption within the T&S receiver market and is offered within 7% of T&S GNSS products. The performance of T-RAIM algorithms are expected to improve dramatically with the availability of dual-frequency measurements. Accordingly, a growth in the number of dual-frequency receivers could fuel growth in the use of T-RAIM algorithms. The increased availability of dual-frequency receivers is also expected to benefit anti-interference monitoring algorithms to improve mitigation and avoidance performances against single-band interferences.

GNSS TIMING DEVICES DEVELOPED TO RESPOND TO SPECIALISED DEMANDS

Typical state-of-the-art receiver specifications for the timing devices macrosegment

Features	Chip	Module	OEM Board	Standard Slot	Packaged System	Modular System
Dimensions	5 x 5 x 0.36 mm	24 x 30 x 4,5 mm	100 x 50 x 20 mm	SFP, PCI/PCIe expansion slot	1 Rack Unit	Single or multiple chassis
Number of channels	12 - 72 channels	12 - 72 channels	12 -112 channels	12 -112 channels	12 -112 channels	More than 100 channels
Constellations	Multi-constellation	Multi-constellation	Multi-constellation	Multi-constellation	Multi-constellation	Multi-constellation
Frequencies	Single frequency band (L1/E1)	Single frequency band (L1/E1)	Single frequency band (L1/E1), some are multi-frequency (L1/E1, L2, L5/E5)	Single frequency band (L1/E1)	Single frequency band (L1/E1), some are multi-frequency (L1/E1, L2, L5/E5)	Single frequency band (L1/E1), some are multi-frequency
Output Time Accuracy	20 ns	15 - 50 ns	10 -150 ns	25 ns - 1us	5 ns -1 ms* *In NTP mode	10 ns - 10ms* *In NTP mode
Holdover	N/A	Basic holdover (VTCXO/TCXO) ±5µs over 24 hour	Depends on oscillator option: Basic holdover (TCXO/OCXO) ±5µs over 24 hour Full holdover (CSAC/Rb) ± 1.1 µs over 24 hours	Depends on oscillator option: Basic holdover (TCXO/OCXO) ±5µs wer 24 hour Full holdover (Rb/Ca) ± 1.1 µs over 24 hours	Depends on oscillator option: Basic holdover (TCXO/OCXO) ±5µs over 24 hour Full holdover (Rb/Ca/CSAC) ± 1.1 µs over 24 hours	Depends on oscillator option: Basic holdover (TCXO/OCXO) ±5µs over 24 hour Full holdover (Rb/Ca/CSAC) ± 1.1 µs over 24 hours
Output interfaces	10 MHZ, 1 PPS	10 MHZ, 1 PPS	10 MHZ, 1 PPS, NTP/SNTP, IRIG-x	10 MHZ, IEEE-1588v2 (PTP), SyncE, 1 PPS, G.8272 V.11, STANAG/ HaveQuick, IRIG-x	10 MHZ, IEEE-1588v2 (PTP), SyncE, 1 PPS, NTP/SNTP, G.8272 V.11, STANAG/ HaveQuick, IRIG-x	10 MHz, IEEE-1588v2 (PTP), SyncE, 1 PPS, NTP/SNTP, G.8272 V.11, STANAG/ HaveQuick, IRIG-x
Operating Temperature range	-40/85ºC	-40/85ºC	-40/85ºC	-40/85ºC	-40/85ºC	-40/85ºC
Antenna	External, active and passive supported	External, active and passive supported	External, active and passive supported	External, active and passive supported	External, active and passive supported Smart antennas being developed	External, active and passive supported Smart antennas being developed
GNSS resilience features	Multi Constellations, anti-interference	Multi Constellations, anti-interference, TRAIM	Multi Constellations, anti-interference, TRAIM	Multi Constellations, anti-interference, anti-spoofing	Multi Constellations, anti-interference, anti-spoofing, TRAIM	Multi Constellations, anti-interference, anti-spoofing, TRAIM
Price Range	30 - 50 euros	75 - 5000 euros	200 - 5000 euros	500 - 3500 euros	500 -12000 euros	3000 - 60000 euros

Disclaimer: The above specifications represent a typical device based on manufacturers' published literature for their latest products. Consequently, discrepancies may exist between the installed receivers' characteristics and those stated above.

The vast majority of T&S products target telecom applications, followed by energy and generic timekeeping. The financial transactions industry's needs can be addressed by 15% of the current product offerings.

GNSS timing devices can range from specialised chips for commercial applications to high-end final modular solutions in a chassis rack. Each solution is developed to ensure the optimum value proposition in a specific targeted market. Therefore there is a plethora of equipment choices and the selection between the devices is usually a trade-off between accuracy requirements, holdover capabilities, interfaces, and cost.

Accuracy level is still a critical aspect to consider when selecting a timing solution

Timing synchronisation accuracy varies with the timing and synchronisation solution in use; for instance nanosecond accuracy cannot be expected when relying on a Network Time Protocol (NTP) interface. Some high-end T&S solutions are now able to reach up to 5 nanoseconds accuracy, with good holdover owing to the capability to track four constellations in dual-frequency mode, the implementation of multipath, and interference mitigation algorithms, as well as the adoption of atomic clocks.

Interfaces and protocols influence the performance of the overall network

If T&S chips and modules only offer a Pulse Per Second (PPS) and 10 MHz interface, high-end T&S receivers are designed to be as flexible as possible. They also provide multiple interfaces so that they can be used for various purposes such as T&S server Precision Time Protocol (PTP), NTP, Primary Reference Time Clocks (PRTC), or Synchronous Ethernet (SyncE) synchronisation units. 'White rabbit' based solutions are currently being developed but could be increasingly adopted in the years to come (see page 82 for more details on the white rabbit protocol).

Resilience is increasingly important in the decision making process and the choice of holdover is paramount

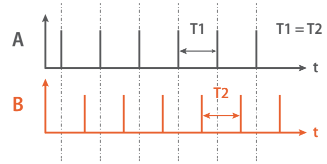
T&S functions are crucial for most critical infrastructure and cannot be disrupted over a long period without a negative impact at national, or even cross-country level. The occurrence of GNSS interference, jamming and spoofing events reached an all-time peak in 2019, confirming the importance of having a GNSS receiver that is robust against signal disruption and corruption. Most specialised T&S commercial applications now offer resilience features such as multi-constellation, anti-interference, anti-spoofing, and T-RAIM solutions.

As these features do not fully protect against GNSS signal disruption, a holdover capability with a level of stability depending on the T&S applications is required. In the case where a basic holdover is required, Oven Controlled Crystal Oscillators [OCXOs] (63% of the T&S solutions) and Temperature Compensated Crystal Oscillators [TCXOs] (36%) are the most common oscillator options for all form factors. Concerning the most stringent holdover requirements, rubidium clocks are the most widely offered option (35%), while caesium clocks and Chip Scale Atomic Clocks (CSACs) account for 8% and 5% of the T&S solutions respectively. For example, some applications such as telecom or electricity transmission often require microsecond accuracy. With a basic holdover capability, GNSS disruption can be held up to 5 hours without surpassing one microsecond accuracy. This can be extended to more than 22 hours with a full holdover, allowing more time for maintenance without putting quality of service at risk.

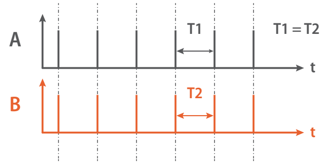
TIMING AND FREQUENCY TRANSFER TECHNOLOGY: A PANORAMA

Time, phase and frequency synchronisations respond to different needs

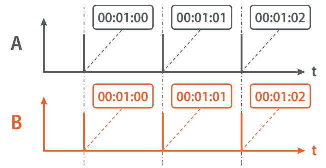
Though Timing and Synchronisation (T&S) is commonly used as a general term for time distribution and clock alignment, three different types of synchronisation actually exist. For these various types of synchronisation, GNSS receiver outputs can be used as frequency reference signals (10 MHz output), reference timing signals (Pulse per second or 'PPS' output), or time reference (e.g. Inter-Range Instrumentation Group or 'IRIG', National Marine Electronics Association or 'NMEA' outputs).



Frequency synchronisation is the distribution of frequency reference signals to the real-time clocks of a network. The leading edge of clocks A and B's pulses are at the same velocity but at different positions.



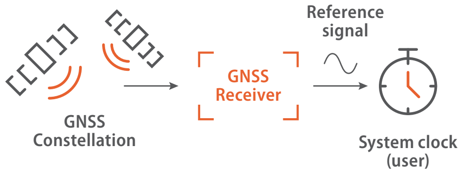
Phase synchronisation is the distribution of a reference timing signal to the real-time clocks of a network. The leading edge of clocks A and B's pulses are at identical positions. Clocks A and B's phases and frequency are aligned but they do not share a common time origin (or 'epoch').



Time synchronisation is the distribution of a time reference to the real-time clocks of a network. The leading edge of clocks A and B's pulses are at an identical moment and identical time. They share a common time scale (e.g. UTC, International Atomic Time, GPS) and related time origin (or 'epoch'). Distributing time synchronisation is one way of achieving phase and frequency synchronisation.

Three main types of time and frequency transfer methods can be used to synchronise a network

Time and frequency transfer is a scheme where multiple sites share a precise reference time and frequency. Multiple methods have been developed over time, two of them involving the use of GNSS.

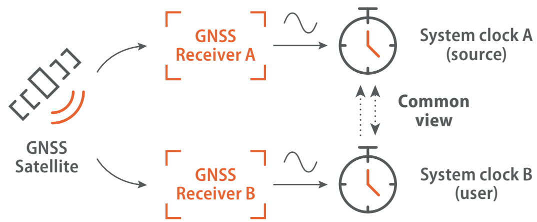


One-Way Method

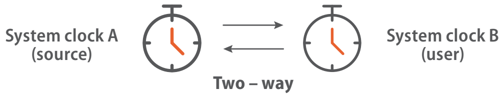
In a one-way time transfer system, a GNSS constellation transmits a standard time reference to a GNSS receiver which then adjusts its local clock to the time reference. This method is the simplest but least accurate and varies with the GNSS constellation in view.

Common view Method

The same GNSS satellite clock is used to transmit a standard and common time reference to two GNSS receivers located at two separate sites. Each GNSS receiver reports the time information to its own system clock. The time difference between the two system clocks is then determined accurately by simultaneously comparing the received times of arrival as measured by clock A and clock B. Such method improves accuracy versus the One-Way method but requires a communication channel between clock A and clock B.



Two-Way Method



The local clock A and remote clock B simultaneously exchange messages to determine their time difference. Both satellite communication and digital networks can be used to exchange these messages. Unlike the common view, the GNSS signal is not used as an intermediary reference and does not have to be simultaneously transmitted to clocks A and B. Clocks A and B however can drift from a standard time reference, requiring GNSS to keep clock source A aligned with a standard time reference.

GNSS TECHNOLOGY HAS A KEY ROLE IN TIMING AND SYNCHRONISATION NETWORK ARCHITECTURES

Understanding the timing and synchronisation standards for a digital network

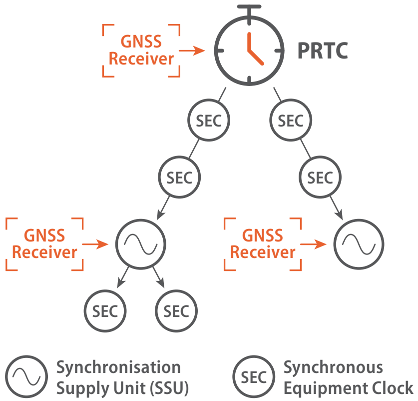
Implementation of synchronisation networks depend on the type of applications served by the digital network (e.g. data, voice and video exchange, time stamping). The industry has established three main standards for the transportation of time and frequency over digital networks; Synchronous Ethernet (SyncE), Network Time Protocol (NTP) and Precise Time Protocol (PTP).

All these standards consist of a hierarchical timing distribution solution, where GNSS receivers are commonly used to synchronise the most accurate clocks (or time servers) located at the top of the hierarchy, or to regenerate the timing signal running through the lower hierarchy levels.

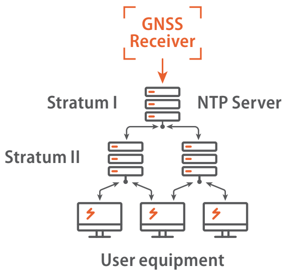
SyncE architecture for physical layer frequency distribution

Ethernet has become the dominant technology for data transmission. The asynchronous nature of the Ethernet however can be an hurdle for services such as voice/video transmissions or hands-off calls, which require the source and destination nodes to be synchronised.

The SyncE standard has been developed as an answer to such a pitfall. This standard is based on a clock hierarchy and relies on the Ethernet data stream for the distribution of a timing signal. A Primary Reference Time Clock (PRTC) is commonly placed at the top of the hierarchy. Synchronisation Supply Units (SSU) are then placed at the next level of the hierarchy, and used to regenerate the PRTC timing signal along its journey from Synchronous Equipment Clocks (SECs) to other SECs that are implemented as part of the transmission network nodes. GNSS signals are commonly used to feed the PRTC as well as the SSUs with a common time reference.



NTP architecture for time and frequency distribution (server-client hierarchy)



NTP, as defined by IETF RFC 5905, is now in its fourth version. This protocol is one of the oldest and most widely used and accepted standards for maintaining time across a network. A basic NTP network is composed of NTP time servers and user equipment (e.g. workstations, routers, other servers). NTP networks are usually structured into stratums in order to prevent potential traffic congestion or disruption. Each time a server is assigned to a stratum level, it corresponds to its distance from an accurate source. Only Stratum I servers have a direct access to a standard time source such as GNSS.

Evolutions of the primary clock reference standard

The ITU Telecommunication Standardisation Sector (ITU-T) is actively contributing to the evolution of primary clock standards that make use of GNSS.

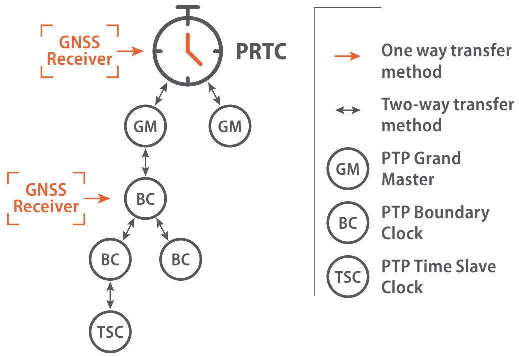
2012	2016	2020+
PRTC	**ePRTC**	**Virtual PRTC**
ITU-T G.8272	ITU-T G.8272.1	No standard defined
Time, phase, freq.	Time, phase, freq.	Time, phase, freq.
Perf. = 100 ns	Perf. = 30 ns	Perf. = 100 ns

The PRTC standard was born in 2012 as a response to the increasing use of Ethernet. Over time, two types of PRTCs (PRTC-A and PRTC-B) have been specified, both of which rely on GNSS. In 2016, with the need to increase performance and protect against GNSS outages, a new standard called enhanced PRTC (ePRTC) has emerged. In addition to GNSS, an ePRTC uses inputs from atomic clocks (e.g. caesium) as frequency references. After 2020, 5G adoption is expected to bring significant changes in the synchronisation paradigm. 5G is expected to require the use of ePRTC close to a large number of cell towers. To ensure successful 5G deployment, the concept of virtual PRTC has been introduced by the industry. It consists of transmitting an ePRTC time reference using PTP over an optical network, thus avoiding the installation of ePRTC close to cell towers.

PTP architecture for time and frequency distribution (master-slave clock hierarchy)

PTP, as defined by IEEE 1588, enables the accurate time-transfer between two clocks by the transmission of messages containing the accurate timestamps of the time at which the packet is sent. The repeated transmission of messages allows the derivation of frequency.

Unlike NTP, PTP clocks are more specialized equipment. The PRTC time reference signal (locked to GNSS signals) is distributed to PTP grandmasters which then rely on the boundary clocks to synchronise one network segment to another. PTP time slave clocks correspond to the end-applications' clocks and are the destination of the boundary clocks synchronisation reference.



IMPROVING T&S NETWORK ACCURACY IS A PRIMARY RESEARCH AREA

Timing and frequency accuracy requirements are expected to increase with 5G adoption and could exceed the current timing and synchronisation network capabilities. As a result, improving the T&S network accuracy has become one of the main areas of research.

Reaching tight synchronisation accuracy is a huge challenge for network operators

Ensuring synchronisation accuracy of primary reference clocks in a network can be a challenge. Indeed, several factors contribute to deterioration in T&S accuracy, several of which are related to GNSS.

- **Natural effects:** The ionosphere is the largest natural source of time errors for a GNSS receiver. Indeed, GNSS signal delays through the ionosphere depend on space weather (e.g. sun activity) and have a 24 hour diurnal cycle. Timing dual-frequency receivers are increasingly being utilised to reduce this error. Development of advanced T-RAIM algorithms is also very important to offer GNSS integrity to Timing users.
- **GNSS receiver (local) environment:** GNSS receiver accuracy may be affected by its local environment and more specifically by interference and multipath effects. Several detection and mitigation techniques have been developed at antenna, pre-correlation, and post-correlation levels to make GNSS receivers more accurate and more robust to the environment in which it is used.
- **GNSS hardware:** Hardware effects between the antenna phase centre and the receiver code correlation point may delay (or advance) GNSS signals. In order to counter such effects, GNSS receivers can be calibrated in two ways; absolute or relative. Such calibration is subject to degradation and needs to be periodically reiterated.
- **Internal clocks:** Noise and transients also affect timing and synchronisation accuracy as it leads to time jitter and wander at the physical layer, and contributes to Packet Delay Variation (PDV) at the network layer that should be appropriately filtered by the synchronisation network.
- **Architecture and implementation:** The PDV at the network layer depends on the components, architecture, and implementation of network elements. Asymmetric slave-master and master-slave links in the networks, as well as the use of different elements such as switches and routers, generate further PDV in a network.

Optical Time Transfer (OTT) solution: towards sub-nanosecond accuracy

OTT projects aim at exploiting fibre technology to provide high-performance and reliable time and frequency services.

OTT takes advantage of the optical fibre technology to assemble a highly symmetric link over long distances (hundreds of kilometres) where delay fluctuations (due to temperature changes over the years, the Earth's rotation, and chromatic dispersion) affect the forwards and backwards directions very similarly. These highly symmetric links allows accurate monitoring of frequency propagation delays by measuring the phase difference between the input and feedback signal (round-trip) and correcting it. Owing to this correction mechanism, network operators are expected to only experience a sub-nanosecond discrepancy when comparing their primary clocks.

White Rabbit: first commercial switches now available

White Rabbit (WR) is the name of a collaborative project including CERN, GSI Helmholtz Centre for Heavy Ion Research, and other partners from universities and industry aiming at developing an open source Ethernet based network for general purpose data transfer and sub-nanosecond accuracy time distribution. It takes advantage of the latest developments for improving timing over Ethernet, such as SyncE and PTP.

Instead of using a traditional two-way PTP scheme which cancels fibre transmission delays but generates synchronisation traffic overheads, the WR project uses continuous measurement of the phase (similar to SyncE) of the bounced back clocks with respect to the transmitting clocks in each of the switches.

The central component of the WR system structure is the WR switch. As for the T&S standards (i.e. NTP/PTP, SyncE), a hierarchical timing distribution architecture is used. The first WR switch in the hierarchy receives its 'clock' from an external source (e.g. GNSS) and transmits time information to other WR switches lower in the hierarchy.

The first WR element to be developed was the 'white rabbit switch', financed by the government of Spain and CERN, and produced by Seven Solutions. Since then, companies such as OPNT and CreoTECH have also developed their own WR commercial solution.

In the years 2015-2016, WR was successfully deployed by the Horizon 2020 project DEMETRA service #3, and tested for distributing Galileo precise UTC using ground fibre service.

SECURING TIME FOR CRITICAL APPLICATIONS IS TO BE CONSIDERED THROUGHOUT THE WHOLE DELIVERY CHAIN

Space segment services

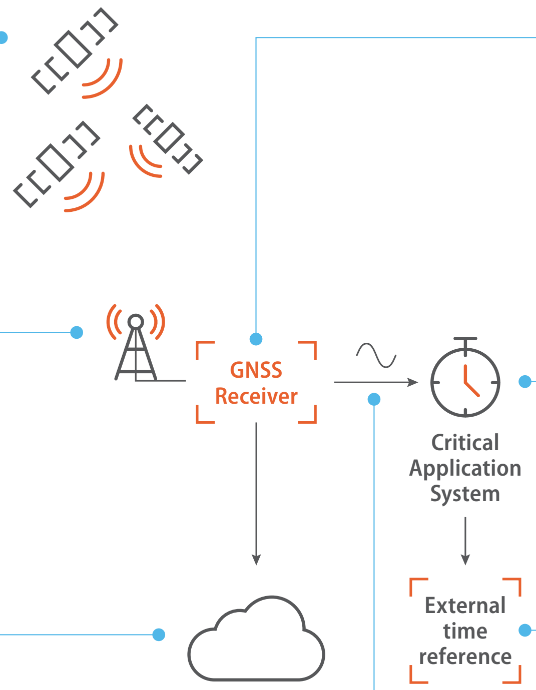
Galileo will offer several authentication services (e.g. OS-NMA and CAS), providing more robustness against spoofing attacks. SBAS regional services (e.g. EGNOS) can be used in order to guarantee GNSS signal integrity and produce improved correction data.

GNSS antenna

Control of radiation pattern antenna (CRPA) can be used to detect a spoofing signal (null steering). Moreover, it is possible to receive several frequencies from several GNSS constellations in order to avoid single band or single constellation jamming attacks.

Cloud services

A GNSS receiver can benefit from the take-off of cloud technology. Indeed, the cloud can be used to relieve the security constraints at receiver level associated to the use of authenticated services (e.g. crypto computing, crypto key storage, security rules). The use of machine learning and AI are also being investigated for their ability to detect and mitigate jamming and spoofing attacks (see below for more information).



GNSS receiver detection & mitigation techniques

A plethora of techniques have been developed at receiver level in order to detect and mitigate jamming and spoofing events. Some examples include:

- **Jamming/spoofing detection:** Jammer to Signal ratio (J/S) level test, clock offset test, Doppler shift test, Direction of Arrival test, signal or message authentication, integrity monitoring (T-RAIM);
- **Jamming/spoofing mitigation:** Frequency domain filtering, hybridisation, spurious response rejection.

Critical application system security

In case of a master clock, the synchronisation network can be secured by authenticating NTP/PTP messages and controlling access to the network.

Time reference redundancy

A critical application system clock is commonly required to feature good holdover capabilities. Such performance can be achieved by implementing an external time reference independent from GNSS in case of a GNSS service disruption. This external time reference can be retrieved from existing radio infrastructure (e.g. eLORAN, ALS162), other existing networks (e.g. SDH/SONET), clock network services (e.g. CLONETS), or atomic clocks (e.g. caesium).

GNSS reference signal security

This signal is delivered from a GNSS receiver to a critical application system clock, and is susceptible to man in the middle attacks as well as counterfeit attacks, and can be secured by implementing mutual authentication mechanisms and/or by ciphering the exchanged messages.

Mitigating GNSS jamming and spoofing using artificial Intelligence and machine learning

Another research area to mitigate GNSS jamming and spoofing includes machine learning and artificial intelligence techniques. These solutions leverage the huge amount of data collected from all the GNSS receivers in networks as well as external data collected from independent sources from GNSS satellites (e.g. satellite ephemeris), from GNSS maintenance (e.g. forecast or unscheduled satellite outages), or from weather/space weather data (e.g. ionospheric conditions, tropospheric path delay). In addition to the position and time, each GNSS receiver in the network may provide the list of GNSS satellites in view, Carrier-to-Noise-Ratios (CNR), azimuth, elevation, or Automatic Gain Control (AGC). Artificial intelligence and machine learning algorithms are used to process this huge amount of data and then deliver different set of services, including remote site analysis and automated detection of potential GNSS service degradation, especially GNSS jamming or spoofing.

HIGH ACCURACY GNSS TIMING WILL SUPPORT FUTURE APPLICATIONS

5G adoption: a new synchronisation paradigm

5G is much-awaited for the new business opportunities that it will enable. However, connecting every devices with low latency and increased data bandwidth will be much more demanding in terms of timing synchronisation accuracy.

Indeed, with the 5G advanced radio features (e.g. enhanced inter-cell interference coordination, joint transmission), the timing synchronisation accuracy requirement is expected to ramp-up from 1.5 microseconds for 4G, to 130 nanoseconds for 5G. Such requirement could even go up to 65 nanoseconds at the next phase of the 5G development.

In addition, even if it is still under discussion, the 5G network would also be required to estimate the position of connected devices within a range of 10 metres (for 80% of users) as a support to location-based services and emergency calls. Such positioning capability could require even tighter timing synchronisation accuracy requirement for the 5G network.

The combined use of White Rabbit switches, PTP and SyncE (Synchronous Ethernet) is expected to provide sufficient timing and synchronisation accuracy performance and is explored by telecom service operators. These standards will use GNSS but might also rely on atomic clocks (e.g. caesium) as external time references. However, improved test devices will be needed to verify that 5G requirements are met, which is considered as a major challenge.

The invisible utility: position, navigation and timing

Critical Infrastructure relies on position, navigation, and timing (PNT), which is now almost exclusively delivered using GNSS. The threat of GNSS errors has become real: signal anomalies, regional disruptions and even global outages already have occurred. Governments across the globe now ask their critical infrastructure providers for plans and solutions to defend against this serious threat.

Multi-constellation technology has become a standard capability for most GNSS receivers. In an uncertain world of GNSS jamming, spoofing, and geopolitical unrest, the ability to track multiple GNSS constellations can provide one more element of operational peace of mind. Together Galileo and GPS are looked upon as the most ideal global GNSS constellations for use within critical infrastructure such as mobile/telecom networks, utility power grids, financial trading, data centres, aviation and emergency services. In addition to tracking multiple GNSS constellations, operators are now able to deploy advanced monitoring solutions that can detect GNSS anomalies, and switch to backup sources until the anomalous condition has cleared.


© Microchip

At Microchip, a leading supplier of precision timing solutions, we support Galileo with proven, highly secure and resilient GNSS solutions for critical infrastructures around the world.

Testimonial provided by the company

The emerging transport applications rely on GNSS T&S

GNSS T&S is widely used in transport applications. For instance, in aviation GNSS is a key component for 4D applications but also as a timing reference for Air Traffic Control.

Moreover emerging transport applications such as smart and autonomous vehicles require strong communication and connectivity for their development. To ensure this communication, a cellular-based protocol called V2X (vehicle-to-everything) has been defined. This new protocol allows vehicles to communicate with other vehicles (V2V), pedestrians (V2P), networks (V2N), and the surrounding infrastructure (V2I).

In order to avoid exchanging and using past or even future information, each vehicle uses its own GNSS receiver as a standard time reference in order to timestamp consistently its data (coming from vehicle sensors or computer) before exchanging them through the V2X communication network.

As the vehicles are moving elements, the network topology must be flexible and the vehicles must often communicate without being able to go through a digital cellular network, in such a case, a sidelink network is established. When establishing a sidelink network, one vehicle of the network is designated as the synchronisation source (as a replacement of the digital cellular base station). This vehicle uses the GNSS timing information to generate synchronisation signals allowing the other vehicles to determine where the V2X frames begin and end.

Robots also need time

In order to perform its tasks, a robot embeds multiple sensors (e.g. video, odometer, range sensor) that are generating data. If its sensors are not synchronised, the robot can act based on out of time or even future sensor data (i.e. data time tagged in the future compared to other sensors data).

Methods used for synchronisation can be software-based by using timing and synchronisation standards such as NTP or PTP or hardware-based by using directly a GNSS receiver unit embedded within the robot to get a proper Pulse Per Second (PPS) signal that can be used to synchronise the robot sensors.

Considering the rising complexity of tasks that robots have to accomplish in the industry or in the health sector, timing synchronisation accuracy requirements are expected to increase.

ADVANCED TIMING FUNCTIONS

To better serve the needs of the user community in the important Timing & Synchronisation sector, GSA is continuously monitoring the development of functions and applications. The functions listed below are currently being followed closely.

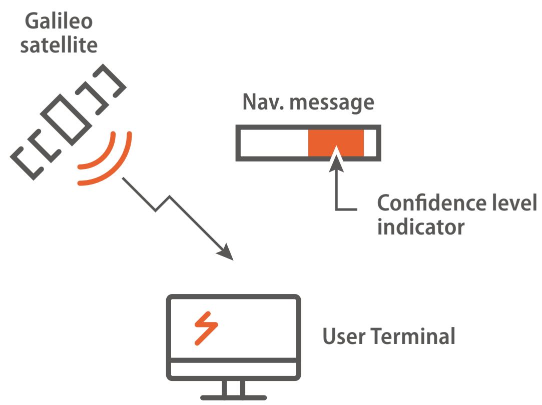
1 - Time integrity

Time integrity ensures a given level of trust, which the timing users can put in the timing information disseminated by the Galileo system.

This indicator or flag could be added to the already existing Galileo OS navigation message as a complement to the Galileo status, integrity and corrections data information.

Owing to the Galileo time integrity feature, timing users would be able to test the integrity of the Galileo signal and be informed of the status of Galileo timing. The system might offer three states: *monitored, not monitored, don't use*, within a given Time-to-Alert (TTA).

Time integrity function



2 - Certified time steering and monitoring

Many applications currently rely on local time sources with limited stability for continuity of operations.

One developing function monitored by GSA aims to improve the stability of these local oscillators through steering corrections from Galileo. This could provide accurate and dependable time-certified solution for a large set of downstream applications.

3 - Trusted time distribution and remote audit

GSA is also closely following the dissemination of UTC time and frequency over Internet using NTP (or PTP) as well as remote assessment of the client clock synchronisation, allowing audits and reports.

This is based on three main functionalities that are fundamental for many applications requiring traceability: trusted time distribution, remote audit and retrospective time verification of the client clock.

4 - Robust accurate time

Synchronisation of networks using GNSS signals that are robust against system failures and/or attacks such as jamming or spoofing is a key challenge. In this respect, an application could be able to synchronise a network of atomic clocks up to thousands of kilometres apart using GNSS with very stringent accuracy requirements, e.g. compliant with the requirements for Telecom applications.

Relevant features for this type of application are: 1) the scalability in terms of number of nodes or geographical coverage, 2) the security offered by a multi-layer approach to authentication, integrity and confidentiality, and 3) the compatibility with already-operational systems.

CRITICAL INFRASTRUCTURES WILL BE MORE ROBUST WITH GALILEO AUTHENTICATION SERVICES

Galileo authentication services for more robustness

With increasing GNSS spoofing threats and the heavy reliance of critical infrastructures on GNSS timing and synchronisation applications, the need for a more robust timing source has become critical. In response to this growing concern, the Galileo programme has designed two E-GNSS civil authentication services:

- **Galileo OS Navigation Message Authentication** (OS-NMA) provides a reinforced authentication capacity compared to the Galileo OS and with free access.
- **Galileo Commercial Authentication Service** (CAS) provides reinforced authentication capacity compared to the Galileo OS-NMA with access potentially conditioned to fee.

Thanks to the E-GNSS authentication services, the time source validity is known by the user and a secure and accurate time traceability to UTC (Coordinated Universal Time) can be obtained. In particular OS-NMA provides a first level of robustness against spoofing with a marginal impact on the receiver (in terms of security constraints and extra computational requirements). This makes it appealing for civil users interested in an improved security but reluctant to deal with the crypto management constraints as well as additional GNSS receivers costs.

FANTASTIC: Galileo OS-NMA benefits for improving robustness against spoofing and meaconing

FANTASTIC

Fundamental Elements

FANTASTIC, a project funded by the FE funding mechanism, is a first commercial step towards secure GNSS timing products implementing time authentication and spoofing detection and rejection. Among others, the FANTASTIC project has assessed the benefits of OS-NMA as an anti-spoofing technique.

An authentication software has been developed and validated against the version 1.1 of the OS-NMA Interface Control Document (ICD). The authentication software authenticates the navigation messages and only allows their use in the positioning engine if they are authenticated. It also has an option to block signals in real time if anomalies on the authentication are detected, which typically mitigates a spoofing attack in about one minute.

More information at: *gnss-fantastic.eu*

Development of a Galileo-based timing receiver for critical infrastructures robustness (GIANO)

GIANO

Fundamental Elements

Thales Alenia Space has been awarded a grant under the GSA's FE funding mechanism for the development of the GIANO receiver, which aims to make critical infrastructure more robust against interference, jamming and spoofing. The timing platform prototype to be developed and validated will integrate all the latest innovative technologies, including professional products from Thales Alenia Space, paving the way for future Galileo-based timing receivers that offer improved resilience and accuracy at a reasonable cost.

More information at: *gianoproject.eu*

GalilEo Authenticated Robust timing System (GEARS)

GEARS

Fundamental Elements

Funded by the FE, a consortium gathering Orolia, FDC, NLR, NLS-FGI and NavCert is developing a prototype of timing and synchronisation receiver. The project is building a new standard for timing and synchronisation applications, leveraging benefit from unique Galileo services such as accurate dual-frequency time transfer and OS-NMA to provide unprecedented resilience and confidence. The multiple layered filtering approach creates a robust, secured and adaptative protection against radio frequency and cyber threats. As such, it will set an assured service for critical operations.

More information at: *gears-gsa-project.eu*

Safety-and liability-critical key performance parameters

Key Performance Parameter (KPP)*	EGNOS contribution	Galileo contribution
Accuracy		⬢⬢⬢
Availability		⬢⬢⬢
Continuity		⬢⬢⬢
Integrity	⬢⬢⬢	
Robustness	⬢⬢⬡	⬢⬢⬢
Time-To-First-Fix (TTFF)		

⬢⬢⬢ Major contribution, capable of enabling new GNSS applications

⬢⬢⬡ Medium contribution, enhancing the user experience

⬢⬡⬡ Low contribution, performances improved but no major difference at user level

* The Key Performance Parameters are defined in Annex 3

EDITOR'S SPECIAL: SPACE DATA FOR EUROPE

THE ROLE OF SPACE DATA IN OVERALL DATA MANAGEMENT IS INCREASING

The volume of data produced globally is growing at a breath-taking rate. In IDC's 'Data Age 2025' white paper, it is estimated that the collective sum of the World's data will reach 175 zettabytes in 2025, from 33 zettabytes in 2018, representing a compound annual growth rate of 61 percent. To provide a yardstick, a zettabyte corresponds to a trillion gigabytes and while presenting the data, IDC comments: *'If one were able to store 175 ZB onto Blu-ray discs, then you'd have a stack of discs that can get you to the moon 23 times.'*

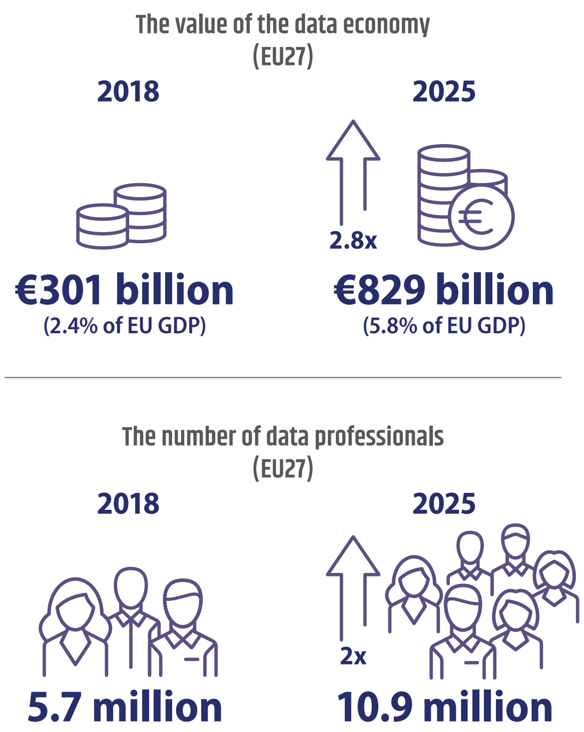
Undoubtedly, the storage, exchange and processing of this massive amount of information, as well as the development of related technologies, will stand at the forefront of the current technological revolution. Combined with other major technological changes in domains such as Artificial Intelligence (AI), connectivity or computing, availability of this vast amount of data offers a multitude of possibilities to fuel economic growth and societal wellbeing.

In the EU, many growth opportunities are connected to the creation of a single EU market for data. According to the European Commission: between 2018 and 2025, the number of professionals employed in the data economy is set to double and overall the data economy is expected to contribute more than 5.8 % of the EU27's GDP. This development will contribute to making the EU economy more competitive globally and will enable innovative processes, products and services.

Data coming from space – alone or integrated with ground-generated information – represents a relevant piece of the jigsaw. Within the EU, Galileo, EGNOS and Copernicus provide data and information that are increasingly used by organisations and consumers. The potential of data is, however, still far from being fully exploited.

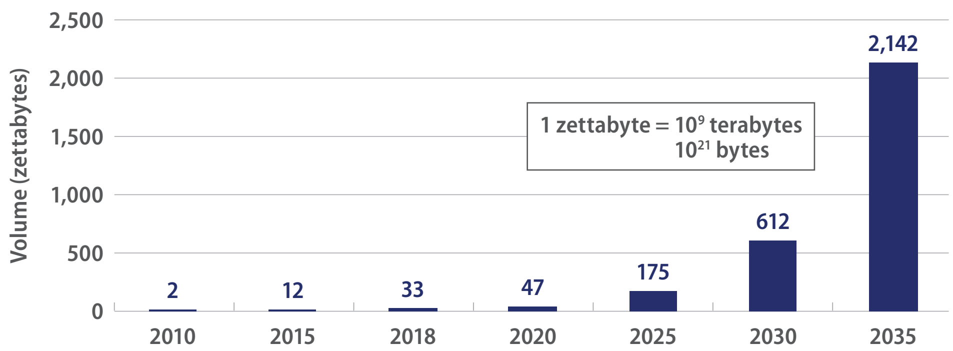
Traditionally, space systems such as Galileo and Copernicus have provided end-to-end services to users. This approach is expanding to the direct use of space data thanks to improving data technologies and industry capacity to build innovative value-added services directly using space data. On the other hand, a limiting factor of space data exploitation has been the difficulty of managing and processing the vast amount of data, to make it usable for end users.

In this Editor's special, we focus on the trends and the challenges connected to the data-driven revolution, on the specific space data contribution, and on how the EU plans to shape its digital future. European GNSS and Earth Observation (EO) capacities have a powerful role to play within this new technological shift. With an increasing penetration of GNSS-based applications in our daily lives as well as the growing importance of geospatial assets to deal with environmental and security-related issues, space-based technologies and applications indeed foster the use of a booming amount of data and bring unprecedented possibilities in many domains.



Source: EC

A booming production of data



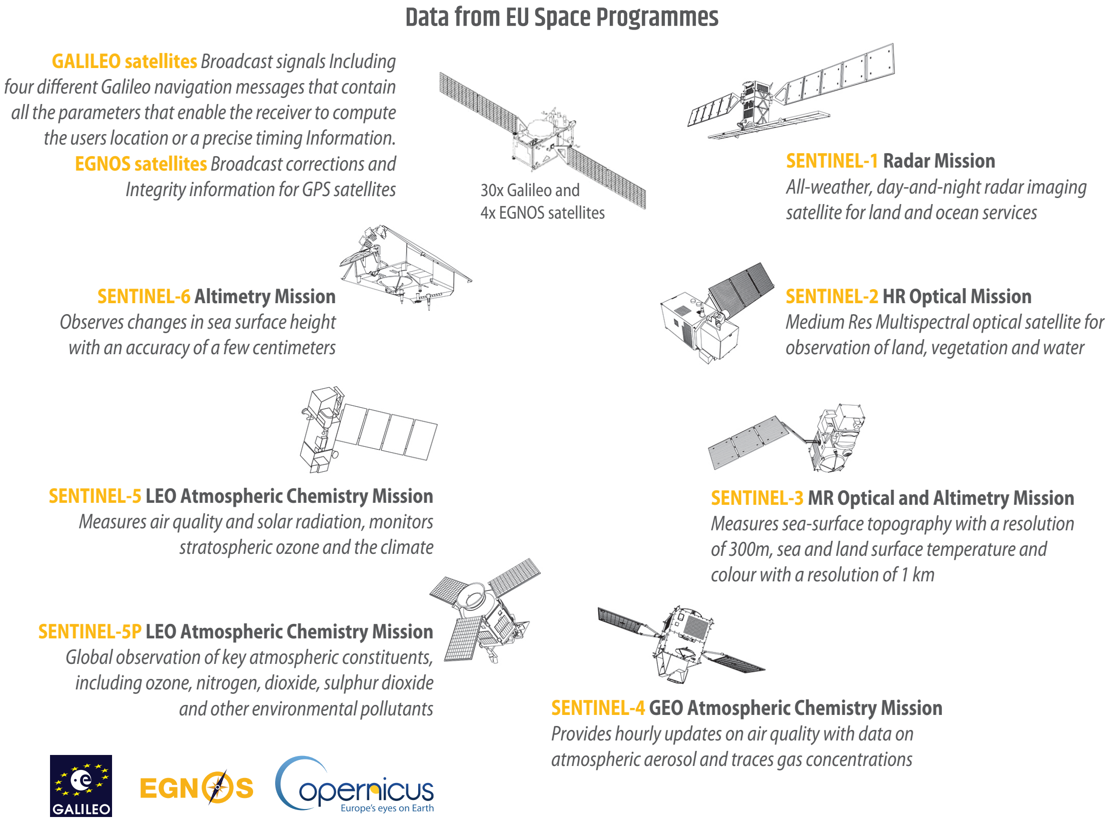
Data Source: © Statista JDN

COPERNICUS GENERATES EASILY ACCESSIBLE SPACE DATA GEOREFERENCED BY EGNSS

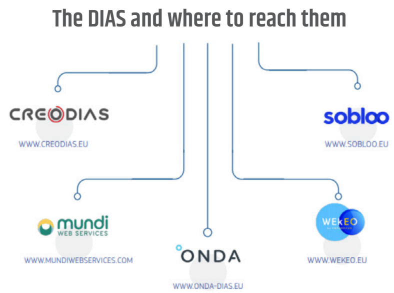
Through cameras and other sensors satellites continuously gather a large amount of data. These global environmental observations are then collected by ground stations and processed using analytical software to produce various geophysical variables that help to describe the Earth's atmospheric, oceanic, and terrestrial domains. Within this context, GNSS contributes by enhancing the value of the data owing to its georeferencing capabilities. This so-called space data is mostly the result of public investments. Traditionally, only governments have been able to undertake this kind of venture, although lately more and more private space firms have improved their ability to build, launch and manage satellites.

Copernicus, the European Union's Earth Observation Programme, aims to achieve a global and high-quality Earth observation capacity based on satellite and in-situ (non-space) data. Copernicus with over 20 TB of Earth Observation (EO) data generated daily, is a major data provider globally and offers data and information services freely and openly accessible in a wide range of application areas. As cloud computing is changing the way businesses and individuals use software, space-related applications benefit from this revolution. For instance, to facilitate the use of Copernicus data, the European Commission has funded the development of five cloud-based platforms called DIAS (see box below).

EGNOS and Galileo integrate with other GNSS to provide positioning and timing information, essential for time and geo-referencing of virtually all other data (e.g. environmental data). This ubiquitous location and timing data is powered by EGNSS in devices such as wearables, smartphones, tablets, vehicles, shipping cargo, or IoT, where EGNSS provides location information of increasing relevance for many sectors such as finance, transport, health, retail, environment and many more.



Copernicus's Data and Information Access Services (DIAS)



The European Union's Copernicus Programme produces up to 20 terabytes of data each day and Copernicus services are provided free of charge to users.

In order to facilitate and standardise access to Copernicus data and information services, the European Commission has funded the deployment of five cloud-based platforms providing centralised access to Copernicus data and information, as well as to processing tools.

These platforms are known as the DIAS, or Data and Information Access Services. The five DIAS online platforms allow users to discover, manipulate, process and download Copernicus data and information together with cloud-based tools (open source and/or on a pay-per-use basis). The five DIAS are called CREODIAS, MUNDI, ONDA, SOBLOO and WEKEO and their architectures enable further extraction of value from Copernicus data and information and increase the ease with which it is handled.

Each of the five platforms also provides access to additional commercial satellite or non-space data sets. Furthermore, DIAS allows the users to develop and host their own applications in the cloud, while removing the need to download bulky files from several access points and process them locally. This opens the doors to additional private users and data aggregators who can further create value from Copernicus space data, thus expanding the value of space data.

TOOLS TO SUPPORT DATA MANAGEMENT: AI, COMPUTING, CONNECTIVITY, CYBERSECURITY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The opportunities offered by data to develop new products and services will be tapped only if the massive amount of data resulting from digitalisation is appropriately processed, exchanged and secured through state-of-the-art technologies like Artificial Intelligence, quantum computing, high-performance networks or blockchain.

There is a mutual dependence (e.g. AI is needed to identify patterns or detect trends in large volumes of data and reciprocally, data availability is essential for training AI systems) and sometimes there is simply a one-way dependence (e.g. using AI to analyse large data volumes requires high computing capacities). Creating a Europe fit for the digital age is a complex undertaking with many interconnected pieces, as highlighted by the European Commission's Communication 'Shaping Europe's digital future'. The GSA have analysed the main pieces of such a system.

Connectivity

Many of the applications made possible by ongoing progress in computer science and data management also require enhanced network capacity. Critical applications like autonomous vehicles or remote surgery for instance will require communication networks offering extremely high availability and reliability as well as low latency. In addition, the proliferation of the IoT will require that a massive number of sensors and smart devices are connected simultaneously.

Owing to the performance they will offer (multi-Gbps peak data rates for each cell, 1-5 ms latency, connection density of 1 million devices per square km, high reliability), 5G and 6G networks should be a game changer for many sectors.

High-Performance Computing, quantum computing

High-performance computing (HPC) is being used to solve problems requiring complex computation such as climate research, weather forecasting, aerodynamic simulation and virtual reality (VR). However, the advent of AI and IoT requires more and more processing capacity. Quantum computing is expected to have a strong impact in domains like AI and Big Data, where processing power is a limitation. For instance, quantum computing could support the development of more humanlike AI by helping to run neural networks or could support more reliable and more accurate weather forecasting and climate projections. It could also help to solve complex navigation problems (e.g. optimise route planning and traffic flows) better and quicker than classical computing, as illustrated earlier in this report.

Edge computing

The last decade has seen a move towards systematically transferring data from the place it is generated to a central processing system. This is evidenced in the move to cloud computing services and the development of IoT and the multi-sensory environment.

Based on a distributed network infrastructure approach, edge computing consists in processing and stacking large data sets locally while transmitting pre-processed data to a computing centre. By doing so, it avoids unnecessary network and storage costs, reduces traffic from the data centre to the device and solves latency issues.

Combined with new networking technologies and AI models optimised to run 'at the edge', edge computing will support the creation of real-time applications.

Artificial Intelligence

Artificial Intelligence is certainly one of the most promising computer science developments with a wide range of applications, including those in which satellite navigation and Earth Observation play a key role. For instance, AI will help to reduce traffic congestion and to develop safer and cleaner public and private transport means. It will help to offer better public services, support personalised healthcare services, improve farming management systems and support the fight against climate change.

However, the potential of AI goes far beyond these few applications, ranging from automated facial recognition and mood analysis to behavior prediction. Speech recognition or language processing and generation will open the door to many other revolutionary applications. For example, in the years to come, AI might well enable the implementation of fully automated drones or self-driving cars.

Cybersecurity

As any other technological progress, the increasing digitalisation of our societies also brings a number of safety and security concerns. Indeed, with billions of connected devices producing data, a key issue is how to protect this distributed (and sometime critical) information from hackers and malicious uses. Additionally, the threat of unauthorized access to people's sensitive data poses a big danger in terms of privacy protection.

One of the emerging technologies enabling cybersecurity is Blockchain, which can secure the IoT by ensuring that the transfer of data generated by devices is protected, among other applications. In healthcare, blockchain can be used to secure the storage of and access to patients' medical data. Logistics is another use case of blockchain, where this technology can be used to protect data such as the location and status of supplies all along the supply chain. The same applies to autonomous vehicles for which the data produced by the onboard sensors and cameras must be stored securely.

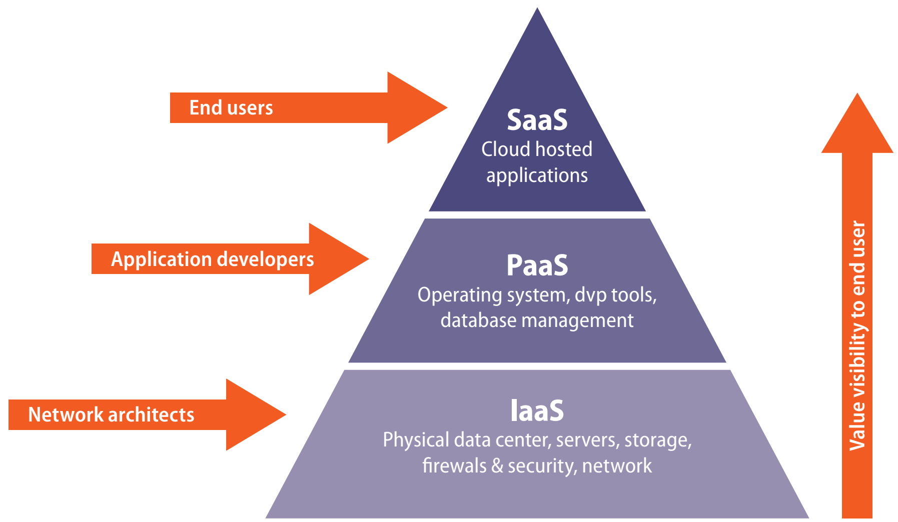
CLOUD SERVICES OFFER A VARIETY OF SOLUTIONS FOR EFFICIENT DATA STORAGE AND PROCESSING

Cloud computing services cover a vast range of options, from the basics of storage, networking, and processing power through to natural language processing and artificial intelligence, as well as standard office applications. One benefit of using cloud computing services is that firms can avoid the upfront cost and complexity of owning and maintaining their own IT infrastructure, and instead simply pay for what they use. In turn, providers of cloud computing services can benefit from significant economies of scale by delivering the same services to a wide range of customers, while hardware failures do not result in data loss owing to networked backups. Three main types of service are offered:

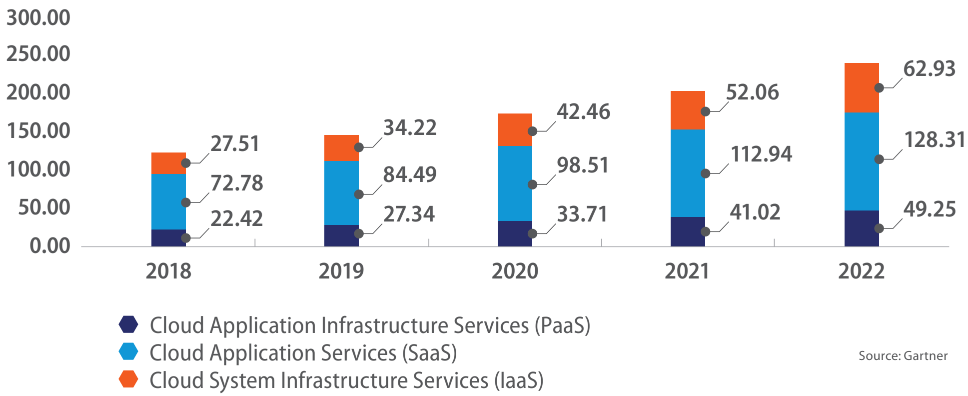
- **Infrastructure as a Service (IaaS):** refers to the ability to provide customers with storage, networks, and other fundamental resources to deploy and run software such as operating systems and applications via the Internet.
- **Platform as a Service (PaaS):** providers allow customers such as application developers to avoid managing virtual servers to create applications by using the coding environment offered by the provider and uploaded on the cloud. The providers maintain the operating systems and related hardware.
- **Software as a Service (SaaS):** is used to deliver an application as a service over the Internet. Instead of installing the software on a locally hosted server, the software is installed on third-party infrastructure and streamed to users and organisations as a service. SaaS has been widely used by many companies and organisations to reduce cost and improve efficiency because the software is only used when needed.

The difference between the layers lies in which part of the stack is managed by client versus which part is managed by the provider. In a Software as a Service model, the Cloud provider manages everything: they manage the web application of that software, the operating system and the hardware that resides in their Cloud data centre, as illustrated on the right.

Three main types of cloud services



Worldwide public cloud service revenue forecast (€ billion)



Source: Gartner

In terms of market size, the global public Cloud services market is forecast to grow 17% in 2020 to a total €226.3 billion, from €193.5bn in 2019, according to Gartner. Of those services, the biggest generator of revenues is SaaS followed by IaaS and PaaS. The market is highly concentrated with the top 3 vendors – Amazon Web Services, Microsoft and Google - controlling over 50% of it.

The cloud computing services market has been rising sharply in Europe and is expected to surpass €67bn by the year 2026, as the market will see a steady uptake of cloud computing platforms. Some noteworthy European players are emerging and can be categorised into three groups according to their origin: in pure cloud-born, telecom-born and software-born cloud providers. The main providers are OVHcloud and Orange in France; SAP, 1&1 and T-Systems (Deutsche Telekom) in Germany; BT in UK and Acens (Telefónica) in Spain.

DESPITE TECHNOLOGIAL PROGRESS EUROPE NEEDS TO FACE SEVERAL CHALLENGES

Digitalisation affects all areas of life and work and is becoming increasingly important globally. Digital transformation cuts across all economic and societal activities, raising opportunities and challenges and calling for appropriate policy responses to prepare the EU economy and society to reap the full benefits of this transformation.

This section details the main technological challenges, especially in the EU context, that need to be overcome in order to best benefit from the many opportunities offered by the current digital transformation.

EU independence in HPC and Cloud resources must be strengthened

There is a significant gap between computing needs and capacities in Europe: while European users consume about 29% of the available HPC resources in the world, only 5% of these resources comes from European providers and no EU supercomputer is in the top 10.

Similarly, the market for cloud services is dominated by foreign actors and the large European actors remain very limited in number. This situation poses serious risks to the EU's capacity to guarantee the long-term availability, integrity and protection of data.

The ICT sector must be 'green'

While a reduction in carbon intensity is part of the benefits expected from the implementation of innovative applications based on the massive availability of data and the use of technologies such as Artificial Intelligence (e.g. through the development of traffic management systems), the fact is that the ICT sector itself has a non negligible environmental footprint, with 5-9% of the world's total electricity consumption and more than 2% of emissions, according to 'The Shift Project'.

One of the challenges of the entire sector (datacentres, smart devices, sensors, communication networks) is therefore success in its own green transformation and the adoption of 'digital sobriety' (the term for using the Internet and technology in a more mindful and responsible way as opposed to cutting it out entirely) as a principle.

The rights and interests of EU companies and citizens must be preserved

Given the multitude in number and type of cyber threats, another important challenge is to guarantee that the digital revolution will fully preserve the rights and interests of EU companies (e.g. commercial trade secrets, ownership) and citizens (e.g. privacy). This requires that efficient approaches for big data cryptography are developed as the encryption methods currently in use for securing small/medium volumes of data may not be optimised in a big data context.

Data interoperability and integrity must be improved

The value of data often comes from its combination with other data. For instance, the combination of data on air quality with data on sources of pollution (e.g. transport, agriculture), on epidemiology and on population density can help assess the impacts of air pollution on health. However, the successful combination of data is highly dependent on the interoperability of data sets.

The interoperability issue, which in the case of geographical data gave birth to the INSPIRE Directive, will be exacerbated with the proliferation of data sources. Another major challenge is the integration and processing of a growing volume of unstructured data (e.g. images, audio, videos). The combination of large volumes of data raises the issue of the validation of datasets, which may include redundant, contradictory, or biased data.

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This latter aspect is particularly critical in the AI domain since the quality of any AI system is intrinsically dependent on the quality of the datasets on which it is trained. Methods and tools enabling the assessment and improvement of data quality are worth investigating.

The generation of large volumes of data and the lack of processing capacities have led to the creation of a stock of unexploited data which, according to current estimates, might represent up to 90% of data in certain cases. Another challenge of digitalisation is to exploit so-called 'dark data' (data which is acquired through the computer network but not exploited to derive insights) so that their storage represents not only a cost but also an opportunity.

Not enough data available for reuse

The value of data lies in its use and re-use. Currently there is not enough usable data available for innovative use and re-use, including the development of artificial intelligence.

This can be improved via: use of public sector information by business (Government to business (G2B) data sharing), sharing and use of privately-held data by other companies (business-to-business (B2B) data sharing), use of privately-held data by government authorities (business-to-government (B2G) data sharing), and through data sharing between public authorities.

Skills shortage and low data literacy

Currently, big data and analytics are top of the list of critical skills shortages. According to IDC, there were approximately half a million unfilled positions in the area of big data and analytics in the EU27. Moreover, general data literacy in the workforce and across the population is relatively low and participation gaps exist.

THE EUROPEAN COMMISSION LEADS THE WAY TOWARDS AN EU DATA REVOLUTION

Shaping Europe's digital future

Digital solutions are key to fighting climate change, achieving the green transition, enabling a vibrant and sustainable economy, and opening new opportunities for business. The **Data Strategy** and the **White Paper on Artificial Intelligence** are the first foundations of the new **digital strategy of the European Commission**.

Creating a single market for data will make the EU more competitive globally and will enable innovative processes, products and services

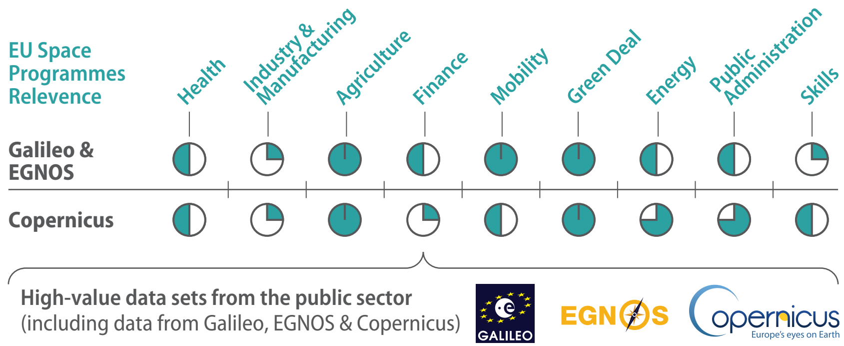
Data has become the core of the digital transformation, influencing our production, consumption and overall lifestyle. Concrete benefits can be brought to citizens owing to better use of data. Benefits include savings related to real-time traffic avoidance or real-time notification of delayed trains. Data is also an essential resource for start-ups and small and medium-sized enterprises (SMEs) in developing products and services and for training artificial intelligence systems, with products and services rapidly moving from pattern recognition and insight generation to more sophisticated forecasting techniques and, thus, better decisions. To fulfil this potential and ensure Europe's global competitiveness and data sovereignty, the **European Strategy for Data** aims at creating a single **market for data**.

This will be achieved through four pillars:

- A cross-sectoral governance framework for data access and use, which sets clear rules on access and re-use of data, making data more widely available by opening high-value publicly held datasets across the EU and allowing their reuse for free;
- Investing in next generation standards, tools and infrastructures to store and process data via federating energy-efficient and trustworthy cloud infrastructures and related services (a European High Impact Project);
- Empowering individuals to learn digital skills and capacity building for SMEs; and
- Fostering the roll-out of nine common European data spaces in strategic economic sectors and domains of public interest (manufacturing, Green Deal, mobility, health, finance, energy, agriculture, public administration). Copernicus and EGNSS have the potential to contribute to all those data spaces (see chart on the right).

Several steps towards the development of the data economy have been taken since 2014. With the General Data Protection Regulation (GDPR), the EU created a solid framework for digital trust. Other initiatives are the Regulation on the free flow of non-personal data (FFD) and the Cybersecurity Act (CSA). A relevant aspect of the EU Data Strategy is how to enable citizens and businesses, especially SMEs, to benefit from high-quality public sector data. Under the 'Open Data Directive' – entered into force on 16 July 2019 – and the related implementing act, it is foreseen that high-value data sets should be made available for free, in machine-readable formats, via APIs and (where relevant) as bulk downloads. Thematic categories of high-value datasets include: geospatial, Earth Observation & environment, meteorological, statistics, companies & company ownership, and mobility. Many of the themes are affected by space data. To ensure easy and free access to data, the EU Open Data Portal (*https://data.europa.eu/euodp/*), the point of access to public data published by the EU institutions, agencies and other bodies, has been established. The Data Strategy may also cover the interconnection of existing infrastructure capacities such as the European Open Science Cloud (EOSC) platform (*www.eosc-portal.eu*) and the EuroHPC initiative (*https://eurohpc-ju.europa.eu/*).

EGNSS and Copernicus potential contribution to Common European Data Spaces



White Paper on Artificial Intelligence – A European approach to excellence and trust

The Commission introduced the **White Paper on Artificial Intelligence** in February 2020, which presents policy options to enable a trustworthy and secure development of AI in Europe, in full respect of the values and rights of EU citizens. The strategy is divided into two frameworks:

- The Policy Framework, aiming to mobilise resources to achieve an ***'ecosystem of excellence'*** along the entire value chain, starting in research and innovation, and to create the right incentives to accelerate the adoption of solutions based on AI, including by small and medium-sized enterprises (SMEs);
- The Regulatory Framework that will create a unique ***'ecosystem of trust'***, ensuring compliance with EU rules, including the rules protecting fundamental rights and consumer rights.

DIGITALISATION: A KEY ENABLER FOR THE 'GREEN DEAL»

European Green Deal

The **European Green Deal**, recently proposed as the new growth strategy for Europe, aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases by 2050 and where economic growth is decoupled from resource use. To achieve this objective, the EU needs to deeply rethink its policies in many domains. As part of this major transformation, the EU has the ambition to promote and invest in digital transformation.

The dual challenge of a green and digital transformation of the EU

The important role of data and digital infrastructures in support to the European Green Deal is indisputably reflected through many cross-sector aspects of the proposed strategy.

First, the digitalisation and the interconnection of the energy market is a key measure to decarbonise the European energy system. The optimisation of the energy mix has indeed become unavoidable if short- and medium- terms climate objectives are to be reached.

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The digital transformation also brings major opportunities to the development of a clean and circular economy, both domestically and globally, through the creation of innovative sustainable business models. The use of electronic product passports could also improve the availability of information and therefore the behaviour of European consumers. Such approaches, as well as the implementation of digital smart-farming practices, are particularly important to foster an **environmentally-friendly food system**. It also contributes to the implementation of the 'Farm to Fork' strategy, improving the place of farmers, fishermen and local producers in the value chain. The construction, use and renovation of buildings is also a central tenet of this dual challenge. Building and renovating in an energy and resource-efficient way must pass through increased digitalisation and climate-proofing of the building stock. **Smart mobility** will also play a leading role in these transformations, especially in urban areas where congestion and pollution must be drastically reduced.

Space-based data on the front lines

Space-based data and information, owing to their ubiquity and continuity, play a significant role in this dual transformation, fostering a myriad of new green-related applications.

In **agriculture**, the implementation of smart-farming practices relies on the combined use of both GNSS location information and EO environmental data, allowing farmers to maximise harvests, while optimising resource consumption.

In **transport**, which represents a quarter of the EU's greenhouse gas emissions, GNSS PNT information helps to optimise traffic management patterns while EO data allows a thorough monitoring of pollution levels.

In the **energy** sector, GNSS timing data is used to precisely synchronise transmission networks, while EO data helps optimise the production of renewable energy.

The 'Destination Earth' initiative

Data and information have become the fuel of our society, allowing us to better model, predict, and understand the impact of human activities on our fragile ecosystem. In addition, the most recent technological advances offer enhanced simulation, modelling and predictive capacities, boosting our ability to tackle the most urgent and complex socio-environmental challenges of our times using the enormous amount of data available.

The *'Digital Twin'* concept aims to create a digital replica of a physical object or an intangible system that can be examined, altered and tested without interacting with it in the real world.

Using these capacities to build digital twins of the different Earth sub-system (i.e. urban areas, local ecosystems, cryosphere, climate-related events, etc.) already enables support of the main priorities of the different European strategies.

Taking the concept a (big) step further, the European Commission has the ambition, through its 'Destination Earth' initiative, to create a digital twin of the Earth in its entirety: an interactive replica of our planet in the digital domain, allowing its analysis in the past, present, and future, based on a powerful combination of observations (satellite, in-situ, crowdsourced data), AI, Earth system science, and modelling.

Yet, many technological gaps will have to be filled and significant progress will have to be made in the modelling of complex and interconnected natural and anthropogenic processes before a digital twin Earth becomes a reality.

In this perspective, the European Space Agency has recently launched the 'Digital Twin Earth Precursors' with the objective to bring together scientists, industry, modellers and policy makers to jointly establish the initial building blocks for the future development of this ground-breaking Earth representation. Once available, this digital twin Earth should become a key element in the development of public policies and the assessment of environmental impact.

EARSC European Association of Remote Sensing Companies

EARSC, the European Association of Remote Sensing Companies, is a membership-based, non-profit organization which coordinates and promotes the activities of European companies engaged in delivering Earth observation-derived geo-information services. EARSC represents this sector in its broadest sense, creating a network between industry, decision makers and users and covering the full EO value chain from data acquisition through processing, fusion, analysis to final geo-information products & services.

EARSC is working to ensure that the needs of the European EO community are met in the development of the Digital Twin Earth and that the maximum benefit will be delivered to society from this ground-breaking project.

Text provided by EARSC. For more information visit: http://earsc.org

ANNEXES

ANNEX 1: GNSS CONSTELLATIONS AND FREQUENCIES

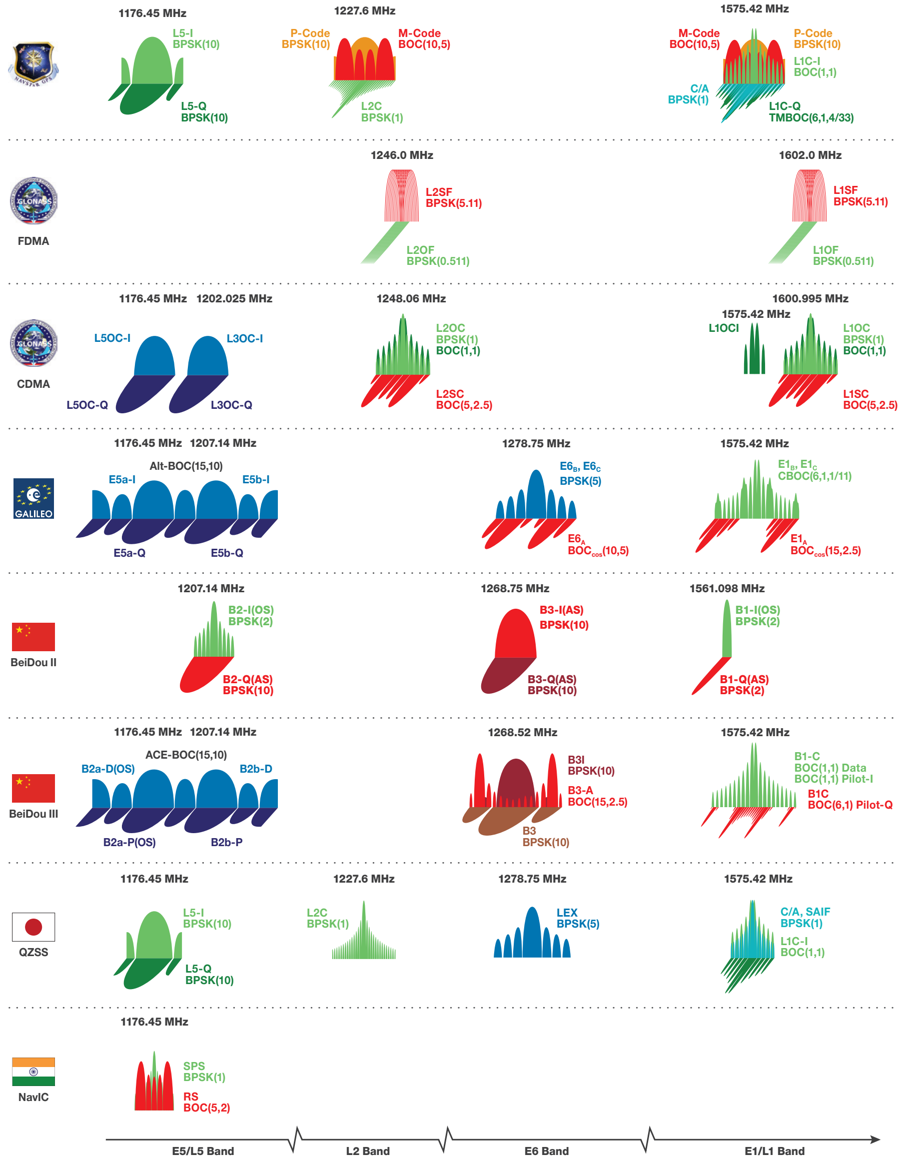
GNSS constellations

Parameter	GPS	GLONASS	Galileo	BeiDou III
Orbital Period (MEO)	11hrs 58min	11hrs 15mins	14hrs 04mins	12hrs 37min
Orbital Height (MEO)	22,200 Km	19,100 Km	23,222 Km	21,528 Km
Inclination (MEO)	55°	64,8°	56°	55°
Number of Orbital Planes (MEO)	6	3	3	3
Number of satellites	24 MEOs + 6 spares	24 MEOs + 2 spares	24 MEOs + 6 spares	24 MEOs + 3 GEOs + 3 IGSOs + spares
Reference frame	WGS-84	PZ-90	GTFR	CGCS 2000
Reference time	GPS Time (GPST)	GLONASS Time (GLONASST)	Galileo System Time (GST)	BeiDou Time (BDT)

RNSS constellations (regional coverage)

Parameter	NAVIC	QZSS
Coverage	India and a region extending 1,500 km (930 mi) around it	Asia-Oceania region
Number of satellites	5 IGSOs + 3 GEOs	3 IGSOs + 1 GEO
Reference frame	WGS-84	JGS
Reference time	IRNSS Network Time (IRNWT)	QZSS Time (QZSST)

GNSS frequency bands



Source: adapted from Navipedia, *http://www.navipedia.net/index.php/GNSS_signal*

ANNEX 2A: AUGMENTATION SYSTEMS AND SERVICES EXPAND TO SERVE NEW MARKETS

Augmentation systems and services allow the improvement of GNSS performance parameters. SBAS and DGNSS systems are examples of augmentations historically developed for improving both GNSS accuracy and integrity. PPP, RTK improve accuracy down to the centimetre level. A-GNSS supports better availability, shorter TTFF and lower power requirements. The technical principles behind each of these augmentations are presented in details in the Editor's special of the first edition of this report (2016). This edition provides a comparative review of these augmentation systems and their key performances, in pages 17-18.

Globally, there is more than ever a plethora of augmentation services available at local, regional or global scale, on a free-to-access basis or on commercial subscription.

Both public and private sector providers are undertaking efforts to make high-accuracy positioning widely available to all categories of users from mass market to professional ones. This trend is triggered by the demand from emerging applications such as self-driving cars or UAVs operating in urban environment and enabled by multi-frequency capabilities of current or future GNSS systems.

Public SBAS service providers plans to provide other value-added services

As introduced earlier in this report (see page 14), several SBAS service providers have announced their intention to provide added-value services, primarily Precise Point Positioning (PPP) service, and thus address new markets. The following table lists the PPP service plans under discussion at the SBAS Interoperability Working Group (IWG) level.

Name	Service	Stated accuracy	Supported Constellations	Owned by
A-SBAS	SBAS		Current: GPS Future: GPS + Galileo	ASECNA
	PPP-AR*		GPS + Galileo	
BDSBAS	SBAS	Horizontal: <5m Vertical: <8m	Current: BDS + GPS + GLONASS Future: BDS + GPS + GLONASS + Galileo	China
	PPP-AR		BeiDou	
EGNOS	SBAS	Horizontal: <1m Vertical: <1.5m	Current: GPS Future (EGNOS V3): GPS + Galileo	European Union
	PPP-AR		GPS + Galileo	
GAGAN	SBAS	Horizontal:1.5m Vertical: 2.5m	GPS	India
KASS	SBAS	Horizontal: <1m Vertical: <1.7m	GPS	Korea
MSAS	SBAS	<2m	Current: GPS Future (MSAS V4): GPS + GLONASS + Galileo + BeiDou+QZSS	Japan
SDCM	SBAS	Horizontal: 0.5m Vertical 0.8m	Current: GPS + GLONASS Future: GPS + GLONASS + Galileo + Beidou	Russian Federation
	PPP-RTK		GPS / GLONASS / Galileo / BeiDou	
SPAN	SBAS	<1 m	Current: GPS Future: GPS + Galileo	Australia and New Zealand
	PPP*		GPS + Galileo	
WAAS	SBAS	Horizontal: <1m Vertical: <1.5m	GPS	USA

* Experimental only stage in March 2020

ANNEX 2B: MAIN COMMERCIAL AUGMENTATION SERVICES

Commercial GNSS Augmentation Services remain a key enabler of high-accuracy operations, whilst also expanding into the mass-market domain

Many operations have long relied on the increased accuracy, integrity and availability secured by commercial augmentation services. Provided at a global, continental or regional scale, these services today consist primarily of PPP and RTK solutions, with some legacy D-GNSS maintaining a solid presence in the market. At the same time, PPP-RTK solutions are emerging alongside commercial augmentation solutions in an effort to make the most of both worlds. Whilst traditionally serving professional users operating in demanding contexts and environments, in recent years there has been a clear trend towards transport or mass-market use of commercial augmentation services. Most providers seek to exploit the full multi-GNSS breadth by utilizing all available constellations in their offering.

Some major commercial operators and services available at a global level are listed in the table on the right. Despite our best efforts, this table is incomplete due to the very fast pace of change in this industry sector. We do apologise to readers and to missing service providers, and recommend visiting our site at: *usegalileo.eu/EN/inner.html#data =surveying* for a more complete and up-to-date list of augmentation providers.

Name	Service	Stated Performance	Supported Constellations	Delivery Method	Method	Provider
Atlas	Atlas Basic	< 50 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	Hemisphere
	Atlas H30	< 30 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	
	Atlas H10	< 8 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	
C-Nav	C-NavC^{1}	< 15 cm	GPS	L band	PPP	Oceaneering
	C-NavC^{2}	< 5 cm	GPS + GLONASS	Internet, L band	PPP	
GeoFlex	PPP Float L1	50 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	GeoFlex
	PPP Float L1/L2	10 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	PPP Fix	4 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	Local PPP Fix&Rapid	4 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	Global PPP Fix&Rapid	4 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
Here	HD GNSS	< 1 m	GPS + GLONASS + Galileo + BeiDou	Internet	PPP	Here
Magic	MagicPPP	< 10 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet	PPP	GMV
NAVCAST	NAVCAST	< 20 cm	GPS + Galileo	Internet	PPP	SpaceOpal
OmniSTAR	VBS	< 1 m	GPS	L band	DGNSS	Trimble
	HP	5-10 cm	GPS	L band	PPP	
	XP	8-10 cm	GPS	L band	PPP	
	G2	8-10 cm	GPS + GLONASS	L band	PPP	
RTX	ViewPoint	< 1 m	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	Trimble
	RangePoint	< 50 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	
	FieldPoint	< 10 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	
	CenterPoint	< 2 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	
SAPA	Sapa Basic	< 1 m	GPS + GLONASS	Internet, L band	PPP-RTK	Sapcorda
	Sapa Premium	< 10 cm	GPS + GLONASS	Internet, L band	PPP-RTK	
	Sapa Premium +	< 10 cm with Integrity	GPS + GLONASS	Internet, L band	PPP-RTK	
Skylark	Skylark	10 cm	GPS + Galileo	Internet	PPP	Swift Navigation
Starfire	SF2	< 10 cm	GPS + GLONASS	L band	PPP	John Deere
	SF3	< 3 cm	GPS + GLONASS	L band	PPP	
Starfix	G2	< 10 cm	GPS + GLONASS	Internet, L band	PPP	Fugro
	G2+	< 3 cm	GPS + GLONASS	Internet, L band	PPP	
	G4	< 10 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	XP2	< 10 cm	GPS + GLONASS	Internet, L band	PPP	
	HP	< 10 cm	GPS	Internet, L band	DGNSS	
	L1	< 1 m	GPS	Internet, L band	DGNSS	
TerraStar	TerraStar-L	50 cm	GPS + GLONASS	L band	PPP	Hexagon AB
	TerraStar-C	5 cm	GPS + GLONASS	L band	PPP	
	Terra Star-C PRO	3 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	
Veripos	Apex	< 5 cm	GPS	L band	PPP	Hexagon AB
	Apex^{2}	< 5 cm	GPS + GLONASS	L band	PPP	
	Apex^{5}	< 5 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	L band	PPP	
	Ultra	< 10 cm	GPS	L band	PPP	
	Ultra^{2}	< 10 cm	GPS + GLONASS	L band	PPP	
	Standard	< 1 m	GPS	L band	DGNSS	
	Standard^{2}	< 1 m	GPS + GLONASS	L band	DGNSS	

ANNEX 3: DEFINITION OF GNSS KEY PERFORMANCE PARAMETERS

Key GNSS requirements and performance parameters

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

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

Availability is the percentage of time the position, navigation or timing solution that can be computed by the user in the coverage area. Values vary greatly according to the specific application and services used.

- System availability: is what GNSS Interface Control Documents (ICDs) refer to. Values typically range from 95 to 99.9%.
- Overall availability: takes into account the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

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

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

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

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

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

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

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

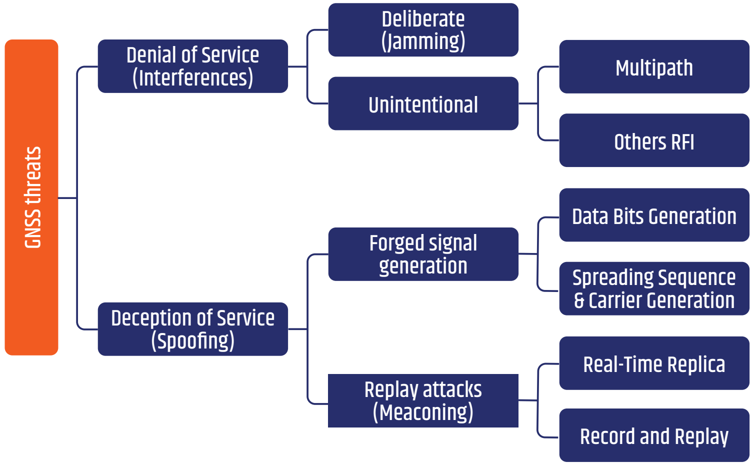
Important Notices:

1. *Applications often trade off parameters against each other depending on their requirements. For example, in safety-critical applications integrity is prioritised over accuracy, whilst in mass market applications low power consumption and TTFF are prioritised over integrity.*
2. *The above definitions are applicable to this report only and are not meant to be used for any other purpose.*

ANNEX 4: RADIO-FREQUENCY INTERFERENCE THREATS TO GNSS

Due to the nature of GNSS (signals received with very low power level), these systems are vulnerable to either natural (e.g. ionospheric scintillation) or man-made (e.g. radio-frequency interferences (RFI) of all sorts) phenomena that may severely disrupt their operation – up to a partial or total denial of service. Such phenomena can be deliberate (jamming and spoofing attacks), but can also be unwanted (spurious radiation of other radio devices, GNSS multipath propagation). Regardless of their nature, these phenomena threaten or degrade GNSS signal reception and should be mitigated against.

A simplified taxonomy of man-made RF threats to GNSS



Spoofing is a more sophisticated and malicious form of attack than jamming (successful spoofing goes undetected). Although jamming is a well-known threat, the classification of spoofing attacks that affect GNSS signals is not straightforward, with the following parameters being vulnerable to attack (independently or not): timing information, ranging information, ephemeris data, almanac data, corrections data, integrity data, service parameters and authentication data.

The different types of threats are further introduced on the right side of this page, while information on how to get protected against them are provided on pages 24 and 83.

Deliberate RF interference - jamming

Although GNSS jammers are illegal to market, sell and use in most countries, they can nevertheless be bought by the public on the internet. A typical motivation for using a jammer is to fool devices used in asset tracking. However, such jammers often disrupt GNSS over a much larger area than advertised, transforming an alleged 'privacy protection device' into a major public nuisance.

Unintentional RF interference

Multipath: a multipath effect is, by definition, a self-interference occurring when the direct path GNSS signal is combined with a delayed replica of itself. It affects carrier as well as code phase measurements. However, by knowing the nature of the interfering signal one can devise specific mitigation strategies.

Other RF interferences: These are unpredictable events, due to abnormal spurious adjacent band or harmonic radiations. Reported incidents have implied sources as diverse as microwave devices, airport radars and TV transmitters.

Generating a forged GNSS signal

Data bits generation: There are two approaches to data bit generation, namely navigation messages replica and forgery.

- Navigation messages replica: Data from space is replayed to reuse the authentic data and/or the ephemeris of the live signal.
- Navigation messages forgery: The attacker can theoretically forge the navigation message to achieve a desired PVT (Position, Velocity, Timing) at the receiver. If message authentication is used, the authentication tag must also be forged.

Spreading sequence and carrier generation: A GNSS system modulates the data with Direct-Sequence Spread Spectrum (DSSS). For all open services, these sequences are published in the system's Interface Control Documents (ICDs), and may be used to construct a simulated signal. Such a forged signal may then be broadcast with or without synchronising the simulated and real-satellite spreading sequences and at various power levels.

Replay attacks – meaconing

Real-time signal replica: signals from space can be delayed and replayed with appropriate hardware, e.g. by using cables that introduce delays into the propagation times, allowing errors in the order of 100 to 200 metres to be introduced in the position solution. Even if this approach isn't sufficient to simulate a desired PVT or trajectory, a user might use it to cheat unprotected liability-critical applications (self-spoofing).

Record and replay: this attack is performed using already commercially available products. The typical architecture of these devices consists of a down-converter and analogue-to-digital converter (ADC), glue-logic, digital storage (hard disk), and a digital-to-analogue converter (DAC) and up-converter for the retransmission of the signal.

ANNEX 5: LIST OF ACRONYMS (1/2)

3D	Three Dimensional
ABAS	Aircraft-Based Augmentation System
ADAS	Advanced Driver Assistance System
ADC	Analogue-to-Digital Converter
ADS-B	Automatic Dependent Surveillance-Broadcast
AGC	Automatic Gain Control
A-GNSS	Assisted GNSS
AI	Artificial Intelligence
AIS	Automatic Identification System
AltBOC	Alternative BOC modulation
AMC	Acceptable Means of Compliance
AR	Augmented Reality
ARAIM	Advanced RAIM
ARNS	Aeronautical Radio Navigation Service
A-SBAS	ASECNA Satellite-Based Augmentation System
ASECNA	Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar
ATM	Air Traffic Management
ATP	Automatic Train Protection
AUV	Autonomous Underwater Vehicle
BDS	BeiDou Navigation Satellite System
BDSBAS	BeiDou Satellite-Based Augmentation System
BeiDou	Chinese GNSS, formerly known as Compass
BDS-3	Third generation BeiDou system
BDT	BeiDou Navigation Satellite System Time
BOC	Binary Offset Carrier modulation
BPSK	Binary Phase-Shift Keying
BYOD	Bring Your Own Device
CAA	Civil Aviation Authority
CAP	Common Agricultural Policy
CAS	Commercial Authentication Service
CAT I, II, III	ILS Categories for precision instrument approach and landing
CSWaP	Cost, Size, Weight and Power
CDMA	Code Division Multiple Access
CED	Clock and Ephemeris Data
CGCS 2000	China Geodetic Coordinate System 2000
CLAS	Centimeter Level Augmentation Service (QZSS)
CLONETS	CLOck NETwork Services
CNR, C/N0	Carrier-to-Noise Ratio
COMPASS	see BeiDou
CORS	Continuously Operating Reference Station
COSPAS-SARSAT	Russian Cosmicheskaya Sistyema Poiska Avariynich Sudow - Search and Rescue Satellite-Aided Tracking
COTS	Commercial off-the-shelf (product)
CPU	Central Processing Unit
CRPA	Controlled radiation pattern antenna
CSA	Cyber Security Act
CSAC	Chip Scale Atomic Clock
DAC	Digital-to-Analogue Converter
DACU	Digital Antenna Controller Unit
DF	Dual Frequency
DFMC	Dual Frequency Multi-Constellation
DGNSS	Differential GNSS
DSSS	Direct-Sequence Spread Spectrum
EARSC	European Association of Remote Sensing Companies
EC	European Commission
EU27	European Union (27 Member States)
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
E-GNSS	European GNSS
eLORAN	enhanced Long-range Navigation
ELT	Emergency Location Transmitters
EMBB	Enhanced mobile broadband
EO	Earth Observation
EPIRB	Emergency Positioning Indicator Radio Beacon
ePRTC	enhanced PRTC
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FDE	Fault Detection and Exclusion
FDMA	Frequency Division Multiple Access
FE	Fundamental Elements funding mechanism
FKP	Flächen-Korrektur-Parameter
FFD	Free flow of non-personal data regulation
GADSS	Global Aeronautical Distress and Safety System
GAGAN	GPS Aided Geo Augmented Navigation
GA	General Aviation
GBAS	Ground Based Augmentation System
GAST	GBAS Approach Service Type
GEARS	GalilEo Authenticated Robust timing System
GEO	Geostationary Orbit
GDPR	General Data Protection Regulation
GIS	Geographic Information System
GLONASS	Russian GLObalnaya NAvigatsionnaya Sputnikovaya Sistema
GM	Guidance Material
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRC	Galileo Reference Centre
GSA	European GNSS Agency
GSO	Geosynchronous Orbit
GSS	Galileo Sensor Station
GSWG	GNSS Sub-Working Group
GTRF	Galileo terrestrial reference frame
H2020	Horizon 2020
H2H	Hull 2 Hull
HAS	High Accuracy Service (Galileo)
HE	Horizon Europe
HEO	Highly Elliptical Orbits
HPC	High Performance Computing
H-ARAIM	Horizontal-ARAIM
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IAT	International Atomic Time
ICAO	International Civil Aviation Organisation
ICD	Interface Control Document
ICG	International Committee on GNSS
IEEE	Institute of Electrical and Electronics Engineer
IERS	International Earth Rotation Service
IF	Intermediate Frequency
IFR	Instrument flight rule
IGS	International GNSS service
IGSO	Inclined Geo-Synchronous Orbit
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IoT	Internet of Things
ISM	Integrity Support Message
ITRS	International Terrestrial Reference System
IRIG	Inter-Range Instrumentation Group
ISOBUS	or ISO BUS or ISO 11783: communication protocol based upon SAE J1939 for the agriculture industry
ITS	Intelligent Transport System
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union-Telecommunication
JGS	Japan satellite navigation Geodetic System
JRC	(EC´s) Joint Research Centre
KASS	Korean Augmentation Satellite System
KPI	Key Performance Indicators
KPP	Key Performance Parameter
LBS	Location Based Service
LEO	Low Earth Orbit
LiDAR	Light Detection And Ranging
LNA	Low-Noise Amplifier
LPV	Localizer Performance with Vertical guidance

ANNEX 5: LIST OF ACRONYMS (2/2)

LPWAN	Low Power Wide Area Network
LTE	Long-Term Evolution, commonly known as 4G LTE
MAC	Master Auxiliary Concept (NRTK protocol)
MAC	Message Authentication Code
MCS	Mission Critical Services
MEMS	Micro-Electro-Mechanical Systems
MEO	Medium Earth Orbit
MEOLUT	Medium Earth Orbit Local User Terminal
MEOSAR	Medium Earth Orbit Search and Rescue satellites
MF	Medium Frequency
MGEX	Multi-GNSS Experiment and Pilot Project
MIoT	Massive Internet of Things
MMS	Mobile Mapping System
MOPS	Minimum Operational Performance Standards
MRT	Main Reference Times
MSAS	MTSAT Satellite Augmentation System
NavIC	Navigation with Indian Constellation: Operational name of the Indian Regional Navigational Satellite System
NMA	Navigation Message Authentication
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
NSP	Navigation System Panel
NTP	Network Time Protocol
NTRIP	Network Transport of RTCM via Internet Protocol
NRTK	Network Real Time Kinematic
NWP	Numerical Weather Prediction
OBU	On-Board Unit
OCX	Next Generation Operational Control Segment (GPS)
OCXO	Oven Controlled Crystal Oscillator
ODTS	Orbit Determination and Time Synchronisation.
OEM	Original Equipment Manufacturer
OS	(Galileo) Open Service
OS-NMA	Open Service Navigation Message Authentication
OSR	Observation Space Representation
OTAR	Over The Air Rekeying
OTT	Optical Time Transfer
PBN	Performance Based Navigation
PCO	Phase Center Offset
PCV	Phase Center Variation
PDV	Packet Delay Variation
PKI	Public Key Infrastructure
PLB	Personal Locator Beacon
PLL	Phase-locked loop
PND	Portable Navigation Device
PNT	Positioning, Navigation and Timing
PPK	Post-Processing Kinematic
PPP	Precise Point Positioning
PPS	Pulse Per Second
PRS	Public Regulated Service
PRTC	Primary Reference Time Clock
PTC	Positive Train Control
PTP	Precision Time Protocol
PVT	Position, Velocity, Timing
PZ-90	Parametry Zemli 1990 (Parameters of the Earth 1990)
QZSS	Quasi-Zenith Satellite System
QZSST	Quasi Zenith Satellite System Time
R&D	Research and Development
R&I	Research and Innovation
RAIM	Receiver Autonomous Integrity Monitoring
RFC	Request for Comments
RFID	Radio-Frequency Identification
RF	Radio-Frequency
RF	Russian Federation
RFI	Radio-Frequency Interference
RGB	Red Green Blue
RINEX	Receiver Independent Exchange Format
RLM	Return Link Message
RLS	Return Link Service
RNP	Required Navigation Performance
RNSS	Regional Navigation Satellite System
RSMC	Regional Short Message Communication
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SAR	Search and Rescue
SAR	Synthetic Aperture Radar (SAR)
SARPs	Standards and Recommended Practices
SBAS	Satellite Based Augmentation System
SCE	Spreading Code Encryption
SDCM	System for Differential Corrections and Monitoring
SEC	Synchronous Equipment Clock
SESAR	Single European Sky ATM Research
SF/DF/TF	Single/Dual/Triple Frequency
SIMOPS	Simultaneous Operation
SLAM	Simultaneous Location And Mapping
SLAS	Sub-metre Level Augmentation Service (QZSS)
SoC	System on Chip
SoL	Safety of Life
SORA	Specific Operations Risk Assessment
SPAN	Southern Positioning Augmentation Network
SQM	Signal Quality Monitoring
SSR	State Space Representation
SPP	Single Point Position
SSU	Synchronisation Supply Units
SyncE	Synchronous Ethernet
T&S	Timing and Synchronisation
TCXO	Temperature Controlled Crystal Oscillator
TESLA	Timed Efficient Stream Loss-Tolerant Authentication
TF	Triple Frequency
TGRS	Tri-GNSS Radio-occultation System
TOA	Time Of Arrival
TRF	Time Reference Facility
TSG	Time Signal Generator
TSI	Technical Specifications for Interoperability
TTA	Time-to-Alert
TTFF	Time-To-First-Fix
TT&C	Telemetry, Tracking & Control
T-RAIM	Time-Receiver Autonomous Integrity Monitoring
TCXO	Temperature Compensated Crystal Oscillator
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UCAR	University Corporation for Atmospheric Research
UHF	Ultra-High Frequency
ULS	Galileo Uplink Station
USAF	US Air Force
UT	User Terminal
UTC	Coordinated Universal Time
UTM	UAS Traffic Management System
UWB	Ultra Wide Band
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VBS	or VRS Virtual Base Station or Virtual Reference Station
VBTS	Virtual Balise Transmission System
VR	Virtual Reality
VRS	Virtual Reference Station
V-ARAIM	Vertical-ARAIM
WAAS	Wide Area Augmentation System
WGS-84	World Geodetic System 1984
WiFi	Wireless Fidelity. Wireless communication protocols standardised by IEEE 802.11 (ISO/CEI 8802-11)
WP	Work Programme
WR	White Rabbit

ANNEX 6: METHODOLOGY USED FOR CREATING THE GNSS USER TECHNOLOGY REPORT

This GNSS User Technology Report is an output of the GSA's internal Technology Monitoring Process (TMP).

It complements the market monitoring and forecasting process behind the GSA`s GNSS Market Report, and its objective is to monitor trends and developments in the GNSS supply industry. It supports the GSA in defining the best strategy to support Galileo market adoption; provides updated statistics on Galileo penetration in user terminals and chipsets; and analyses Galileo's positioning among other GNSS and location technologies.

Part of the process is to keep up-to-date independent analysis, which assesses the capabilities of receivers, chipsets and modules currently available on the market. For the analysis, whose outputs are visible not only on pages dedicated to receiver`s capabilities in all macrosegments, each device is weighted equally, regardless of whether it is a chipset or a receiver, and no matter what its sales volume is. The results should therefore be interpreted not as the split of constellations utilised by end-users, but rather the split of constellations available in manufacturers' offerings.

The analysis includes all major receiver manufacturers in Europe and worldwide: Apple (Intel), Bdstar (Unicore), Brandywine Communications, Broadcom, Cobham, Collins Aerospace, DJI, Eca, Elprom, Esterline, Frequency Electronics, Furuno, Garmin, Gmt, Gorgy Timing, Hemisphere (Agjunction, Stonex), Hexagon AB (Leica, Novatel), Hi-target, Honeywell, Huace (Chcnav), Huawei (Hisilicon), Jackson Labs, John Deere (Navcom), JRC, Kongsberg, Microchip, Mediatek, Meinberg, Microsemi, Navico, Orolia, Oscilloquartz, Qualcomm, Raven Industries, Samsung, Seiko Solutions, Septentrio, Seven Solutions, STMicroelectronics, Thales Avionics, Topcon, Trimble, u-blox, Unisoc.

Military / defence receivers, chipsets and modules are not discussed in this report.

The information contained within this report is a compilation of in-house knowledge, scientific papers, receiver and other user technology manufacturers' websites and, if needed, has been verified by consultation with experts in the relevant domain.

Disclaimer

The GNSS User Technology Report Issue 3 preparation was carried out by the European GNSS Agency in cooperation with the European Commission and with the support of FDC, Egis, Evenflow, Université Gustave Eiffel, VVA and LE Europe.

Although the Agency has taken utmost care in checking the reasonableness of assumptions and results, the Agency accepts no responsibility for the further use made of the content of the Report.

Any comments to improve the next issue are welcome and should be addressed to: *market@gsa.europe.eu*

The European Commission

European Commission (EC) is responsible for management of the European satellite navigation programmes, Galileo and EGNOS, including:

- Management of funds allocated to the programmes;
- Supervising the implementation of all activities related to the programmes;
- Ensuring clear division of responsibilities and tasks in particular between the European GNSS Agency and European Space Agency;
- Ensuring proper reporting on the programme to the Member States of the EU, to the European Parliament and to the Council of the European Union.

The Galileo and EGNOS programmes are entirely financed by the European Union.

The European GNSS Agency (GSA)

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 infrastructures;
- 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 authors would like to convey special thanks to the contributors of this report:

- Galileo Services;
- Companies providing testimonials: Broadcom, ICaune, FieldBee, f.u.n.k.e, Google, Hexagon, Microchip, Rokubun, Septentrio, Sony, Trimble, Unifly.

Integrated Market Development at the GSA

The **GSA GNSS User Technology Report** is a product of ongoing market development and technology monitoring activities that aim to:

- **Stay close to the user and the value chain:** involving GNSS users, downstream industry, experts and other stakeholders in key market segments by managing relationships with stakeholders, organising and participating in user and industry fora, identifying needs and assessing stakeholder satisfaction.
- **Monitor GNSS market and technology:** forecasting future developments by market segment, including regular collection, modelling and expert validation of current information, drivers and assumptions; analysis of the GNSS downstream industry market share; cost-benefit analyses of the European GNSS Programmes and future scenarios; monitoring trends in positioning technology; and tracking of E-GNSS penetration.
- **Build and implement E-GNSS market strategy with market players and institutional stakeholders:** fostering the use of E-GNSS in all GNSS market segments; promoting integration of E-GNSS inside chipsets, receivers and devices; organising workshops and testing; and supporting EU industry business development and competitiveness.
- **Manage EU-funded R&D on GNSS applications and services within FP7 & H2020 programmes:** leveraging results for E-GNSS adoption and EU industry competitiveness, including ~400 demonstrations of E-GNSS applications; 90 products, 300 prototypes, 25 patents/trademarks – with more results on the way.
- **Manage EU-funded R&D on GNSS chipsets, receivers and antennas:** gearing these end-products to end-users from all segments, aiming to support the EU industry with grants or tenders/procurements tailored to meet current and future user needs.

The European GNSS Agency: linking space to user needs.

European Commission

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ISBN 978-92-9206-049-7 TS-AD-20-001-EN-N