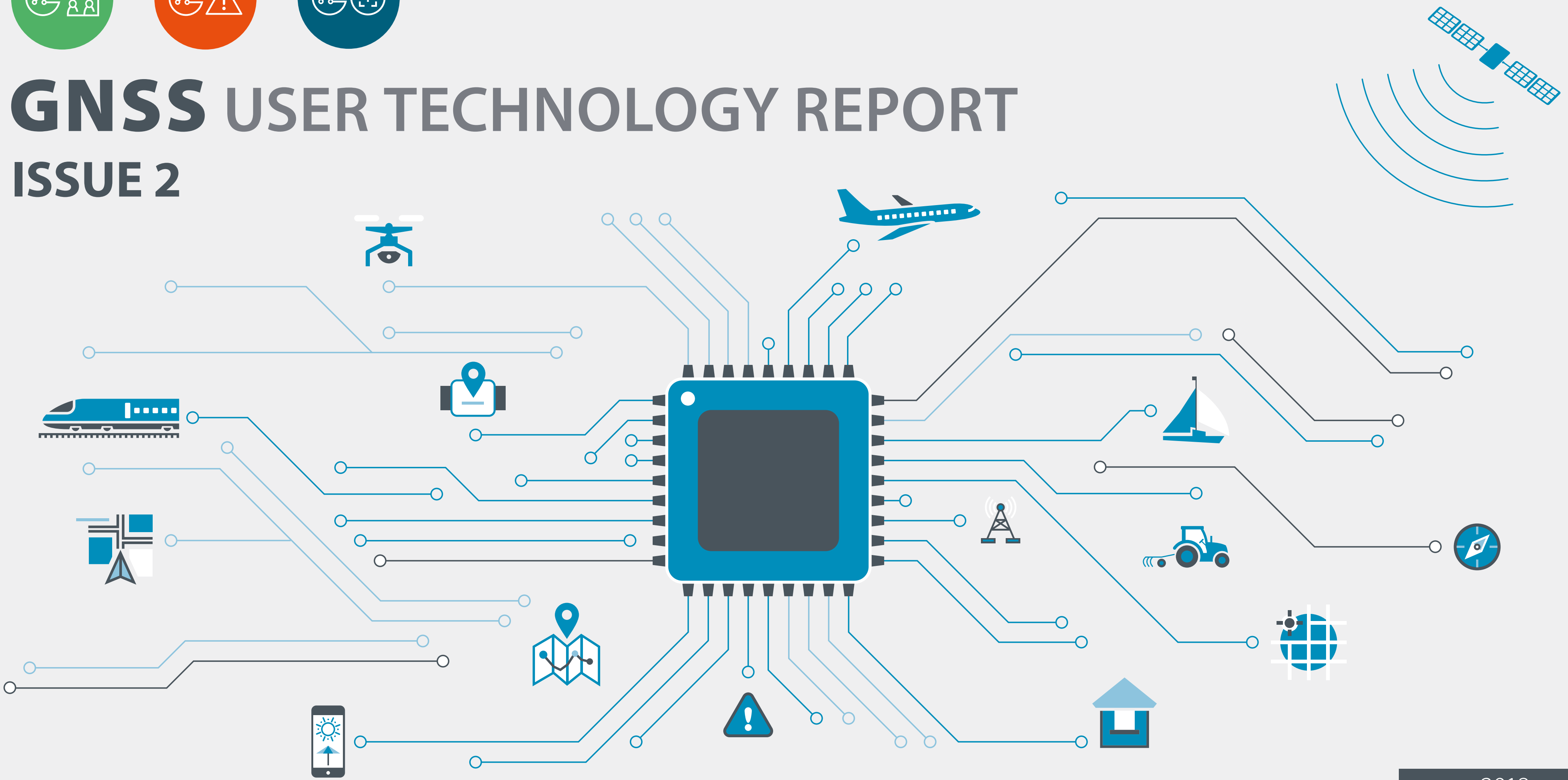
EDITOR'S SPECIAL
AUTOMATION

GNSS USER TECHNOLOGY REPORT

ISSUE 2



2018

European
Global Navigation
Satellite Systems
Agency

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FOREWORD

Dear Reader,

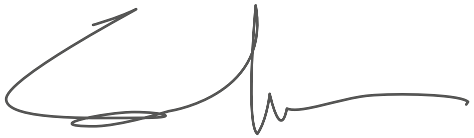
We are truly living in the Golden Age of GNSS. With everyone now carrying a space receiver in their pocket and using satellites to move, play and work, GNSS has become a ubiquitous technology. However, I believe the real development – and the most important one, as it allows all of these devices to work better – is the shift towards a higher accuracy for all stemming from dual- and multi-frequency. Galileo is at the forehead of this evolution, being the advanced GNSS enabling for instance autonomous transport applications.

Supporting evidence, coming from the LBS market, is the introduction of the first dual frequency smartphone in May 2018. This is only the beginning. As we approach the threshold of living on a planet where every person has a GNSS device, satellite navigation will serve as the backbone of a digitally connected world. With information on positioning, velocity and timing driving growth in a wide array of context-aware applications, GNSS will be an important enabler for everything from the Internet of Things to Augmented Reality and autonomous vehicles.

The GSA's GNSS User Technology Report Issue 2 takes an in-depth look at the latest state-of-the-art GNSS receiver technology, along with providing expert analysis of the evolutionary trends that are set to define the global GNSS landscapes – and our daily lives – in the coming years. In the following pages, you will find an in-depth look at applications and solutions within the safety- and, liability-critical transport, high precision, timing and mass market macrosegments. This edition also features an 'editor's special' devoted to automation and to the increasingly important role GNSS plays in a number of partially- or fully-automated tasks and functions.

This publication was written with the contribution of leading 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 E-GNSS evolution.

Carlo des Dorides
Executive Director



The European GNSS Agency (GSA)
Prague, October 2018

EXECUTIVE SUMMARY

The coming years will see two new GNSS (Galileo and BeiDou), and two RNSS (QZSS and NavIC), reach full operational capability. In parallel, the modernisation of existing GNSS (GPS and GLONASS) is also well underway. Thus, in just a few years there will be **four global and three regional satellite navigation systems**, and more than 100 satellites providing open access to more accurate and reliable PNT services, including through the use of multiple frequencies. Public augmentation systems, such as EGNOS, are also evolving to become multi-constellation and multi-frequency.

A very clear trend identified in the previous issue of this report was widespread support for **multiple constellations**, which is confirmed here as the baseline for today's new receivers. The most important new trend identified in this issue is **the rapid adoption of multiple frequencies** (almost 10 percentage points more in the last two years) – including for consumer devices, as evidenced by the market introduction of the first dual-frequency smartphone in May 2018. The second frequency of choice for these new devices is E5a/L5, which has either already been adopted or is planned to be supported by all global constellations, with efforts led by Galileo.

Beyond the maturity and evolution of the core upstream infrastructure (GNSS, RNSS, SBAS), and owing to the possibilities it offers, we also observe the **growth of new value-added services** proposed by the system providers themselves, or by private industry. This is particularly true of **high-accuracy services**, which until recently were offered primarily to professional users in the surveying, mapping, engineering or precision agriculture domains, but are now propagating out to the mass market – not just for driverless cars, but also for all kinds of augmented reality applications. New service providers emerge, new alliances appear, and new distribution methods are proposed, including via mobile telephone networks, to serve the emerging "high accuracy for all" markets. The free Galileo High-Accuracy Service (HAS) and QZSS Centimetre-Level Accuracy Service (CLAS) are just two examples of this tendency.

In addition to the trend for high accuracy, there is a growing awareness of the need to ensure both **safety and security** of the PNT solutions. This trend is especially important where PNT will be at the core of systems where humans are out of the control loop, such as in autonomous vessels, cars or drones. Galileo authentication services, namely the Navigation Message Authentication (NMA) and the Signal Authentication Services (SAS), are important contributions to this security. At least one leading private GNSS augmentation service provider has begun marketing "trusted positioning" through "real-time ephemeris data and navigation message authentication", confirming that high accuracy is not the endgame, but rather **'trusted and resilient' high accuracy remains the ultimate goal**.

This flourishing offer of core and augmentation services means that the choices available to receiver manufacturers, system integrators and application developers are more diverse than ever before.

In the **mass market domain**, we are seeing a divide between chipsets optimised for 'entry level' IoT products, where energy per fix is the primary driver, and 'high end', where positioning performance is more important. The former receivers tend to be single (or dual) constellation, single frequency, narrow band; all factors that contribute to satisfying the requirements for very low power consumption. The latter have widely adopted **multiple constellations** (four GNSS), wider band processing, with up to 80 channels, and the most advanced versions now offer **dual frequency** capability, which leads to greater accuracy.

The **transport and safety critical domain** is traditionally constrained by regulations and standards, and therefore slower in adopting new technologies. The emergence of the driverless car, professional or 'prosumer' drones, and autonomous vessel developments have shaken this segment of the industry, and it is now evolving at a very fast pace for these, as yet unregulated, applications. **Multiple constellation, multiple frequency, INS hybridisation**, and **sensor fusion** are all being used to contribute to the required **'assured' and safe positioning solutions**. Whilst current solutions demonstrate that the high accuracy essential to autonomous applications is achievable, work is still required to reach the high levels of integrity, continuity, and security that must be guaranteed for safety-of-life applications.

In the **professional domain**, high accuracy is achieved with **triple or quadruple frequency** receivers, using **all constellations** and signals as well as **RTK**, **NRTK** and increasingly real time **PPP** augmentation services. Receivers have several hundreds of channels, and have started to allocate some of these to detecting unwanted (jamming, spoofing, or multipath) signals.

The combined availability of powerful mobile computers, tablets, or even smartphones, and of affordable dual frequency chipsets developed for the mass market, make it possible to run high-accuracy PVT solutions on such devices. By adding application-specific software, these developments combine to enable mapping, GIS data collection, and potentially surveying applications on consumer electronics devices. This is further supported by the availability of GNSS raw measurements on Android devices.

Many of the technical advances observed in this report are driven by the will to use GNSS-derived position or time not only for *information* purposes, but also for *monitoring*, and increasingly today for *controlling* tasks, such as those encountered in robotics or navigation of all kinds of unmanned carriers. The 'Editor's special' section of this issue is devoted to **automation**, and to the increasingly important role GNSS plays in a number of partially- or fully-automated tasks and functions. The most publicised examples are found in the transport domain, with driverless cars, autonomous vessels and drones, but as the interested reader will see, GNSS-based automation applications go well beyond transport.

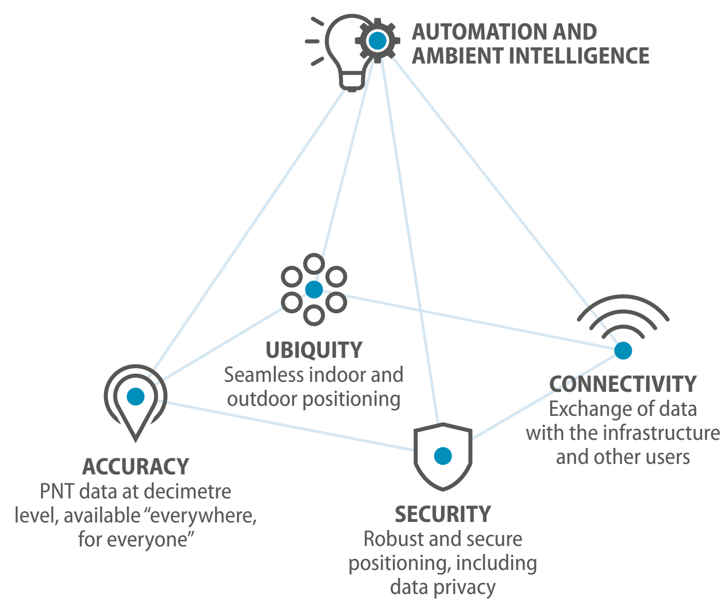
The analysis of GNSS user technology trends is supported by testimonials from key suppliers of receiver technology: Broadcom, Javad, Kongsberg, Leica, Maxim Integrated, Meinberg, Novatel, Orolia-Spectracom, Qualcomm, Septentrio, STMicroelectronics, Thales, Trimble and u-blox presenting their latest innovations in the field.

DAWNING OF NEW ERA: TOWARDS AUTOMATED SYSTEMS

There are four main dimensions of PNT systems technology development that enable the future of automated, intelligent positioning systems. As presented in the PNT technology drivers on the right, the location systems must be ubiquitous, secure, accurate and connected to provide basis for modern automation and ambient intelligence.

The advent of automated systems has progressed very rapidly in the last months thanks to the development alongside all four dimensions of the pyramid base. The Editors' special of this issue of the GSA Technology Report is therefore devoted to automation.

PNT TECHNOLOGY DRIVERS PYRAMID



Main areas of innovation

GNSS is and will remain for the foreseeable future an integral part of PNT solutions. It cannot, however, provide alone the ubiquitous, accurate, safe, assured PNT information that is required.

Maintaining performance in all contexts requires the fusion of **multiple positioning technologies and sensors.**

Accuracy is obtained thanks to **multi constellation, multi-frequency GNSS,** augmented by **PPP-RTK services** and **hybridised** with **INS** and other **sensors**.

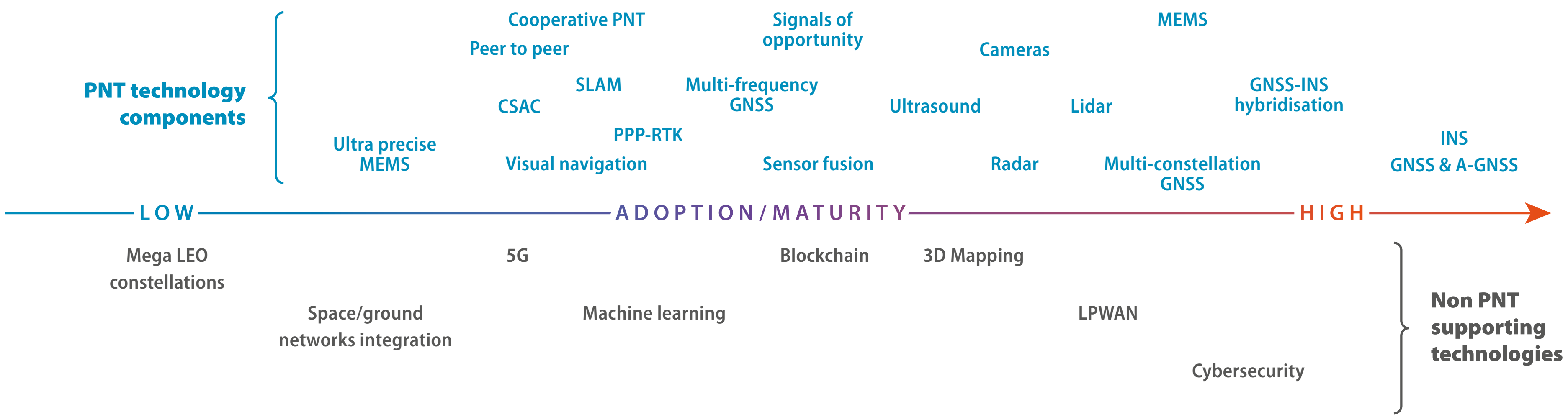
Connectivity relies on the **integration** with both **satellite and terrestrial** networks, such as **5G**, **LEOs**, or **LPWANs**.

Ubiquity is provided by **complementary** positioning **technologies** and **sensors**.

Security is provided by the combination of **independent redundant technologies, cybersecurity**, and **authentication**.

This complex ecosystem is depicted in the following diagram:

THE PNT ECOSYSTEM: STATE OF MATURITY



HOW TO READ THIS REPORT

This report has been divided into three sections which cover the main areas related to GNSS technology.

In the opening section, **GNSS User Technology overview**, we present a summary of recent developments and future trends in GNSS. We focused on multi-constellations and multi-frequency applications that drive the new trends, and also achieve greater accuracy whilst maintaining high integrity. Updates on Galileo, GLONASS, BeiDou, GPS and Regional Navigation Satellite Systems are described in detail. You can also find information regarding the evolution in signal processing and how antenna capabilities drive receiver performance. Another topical area featured is anti-spoofing and anti-jamming trends, and how vulnerabilities can be mitigated. The section concludes with a description of elements that drive innovation, and highlights innovation centres in Europe.

The second section consists of three sub-sections where specific applications and solutions are presented, grouped into macrosegments.

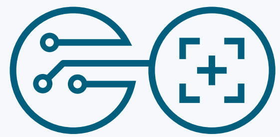
1. **Mass market** – presenting high-volume receivers for consumer devices. Automotive (not safety critical), consumer drones, smartphones, and specialised IoT devices from mHealth to robotics are all covered.
2. **Transport safety- and liability-critical solutions** – presenting receivers built in accordance with standards to deliver such solutions. Automotive, aviation, professional drones, maritime, search and rescue and, new to this issue of the TR, space-borne GNSS applications are all covered.
3. **High precision and timing solutions** – presenting receivers designed to deliver the highest accuracy (position or time) possible. Agriculture, GIS, Surveying and Timing and Synchronisation applications are all covered.

The third Editor´s special section focuses on the important trend of **Automation**. Here we provide both a current overview and a future vision of automation, explain the interconnection between GNSS and automation, show the benefits of fusion of many different data, explain why artificial intelligence is not the same as automation and focus on automation trends mainly in road transportation, but also in the drone and maritime domains.

Finally, in the annexes you will find a general overview of GNSS positioning technologies, augmentation services, key performance parameters, and definitions, as well as the methodology used to write this technology report.

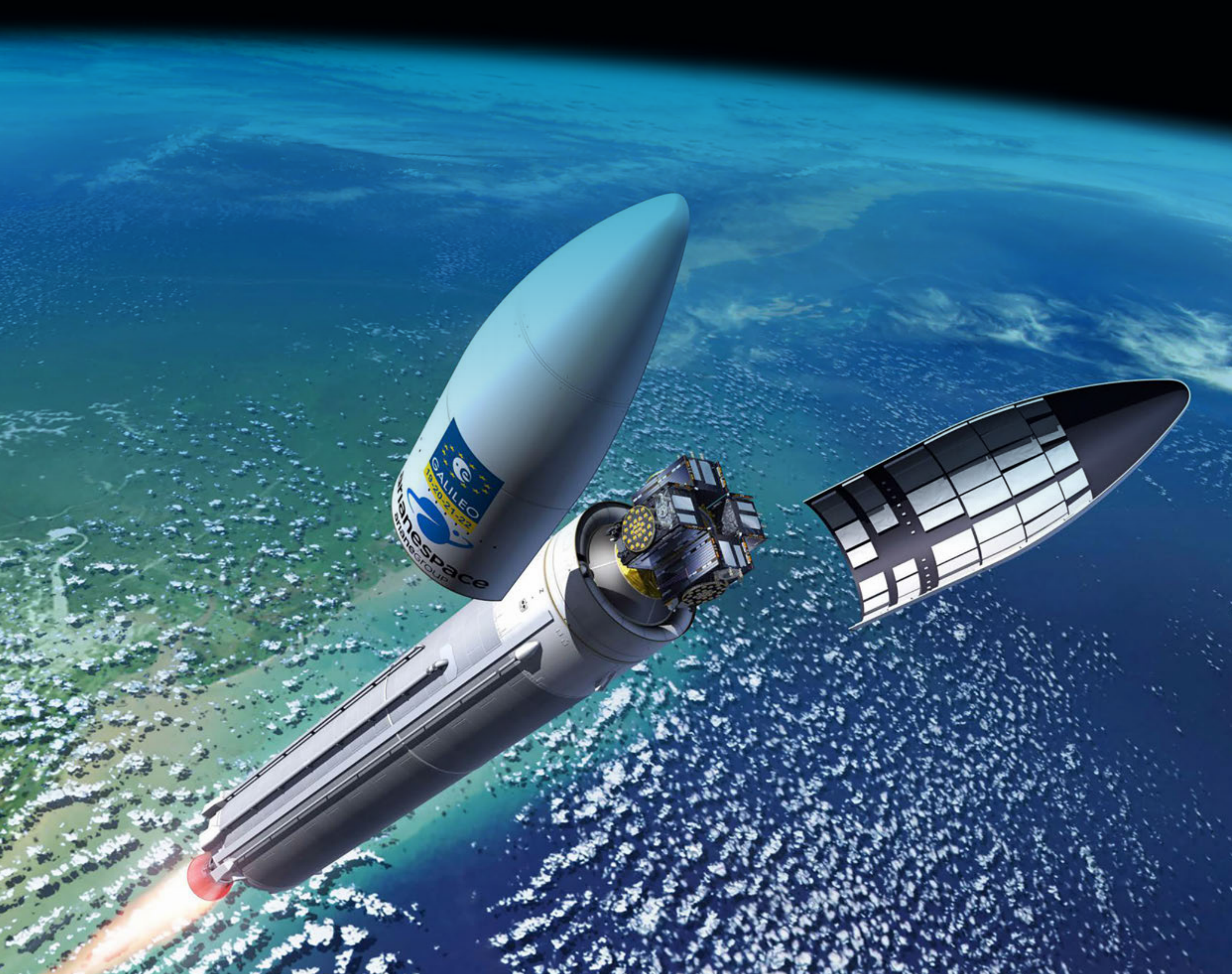
Mass market
consumer solutions

Transport safety- and
liability-critical solutions



High precision and timing solutions

GNSS USER TECHNOLOGY OVERVIEW



INTEROPERABLE MULTI-GNSS IS THE REALITY TODAY

Multiple constellations provide navigation services

The four **GNSS – GPS** (USA), **GLONASS** (RF), **BeiDou** (PRC) and **Galileo** (EU) – are currently in either full operational capability (FOC) or nearing FOC status, with the two most recent constellations due to complete deployment by 2020. As a result there were already over 100 GNSS satellites in orbit as of December 2017.

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

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

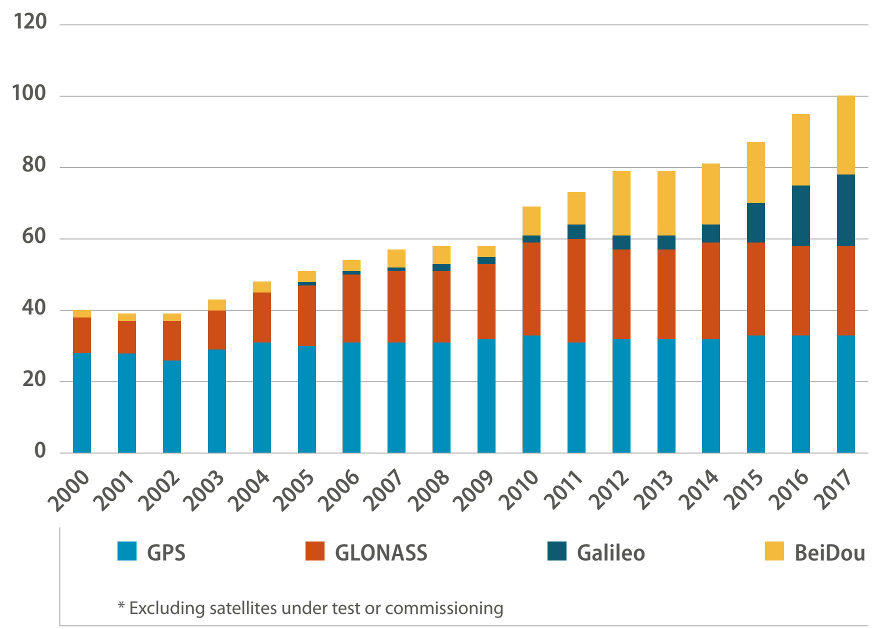
Signals and services: interoperability of open services for a true multi-GNSS world

GNSS, RNSS and SBAS providers are coordinating their efforts, notably through the United Nations Office for Outer Space Affairs (UNOOSA) and its International Committee on Global Navigation Satellite Systems (ICG). The ICG "strives to encourage and facilitate compatibility, interoperability and transparency between all the satellite navigation systems, to promote and protect the use of their open service applications and thereby benefit the global community"[1].

Notably this coordination leads to the adoption of current or modernised 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-GNSS chipsets and receivers, to the benefit of the end users.

Although interoperability is the commonly agreed goal, each GNSS/RNSS can provide specific services through dedicated signals. This is indeed the case of (restricted access) governmental services[2] such as Galileo Public Regulated Service (PRS) or GPS Precise Positioning Service (PPS), but also of value added services (e.g. Galileo High-Accuracy Service (HAS), QZSS L6 or BeiDou short messaging service) which may be provided for free or for a fee.

OPERATIONAL* GNSS SATELLITES



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). The frequency ranges are often referred to by the signal names they contain, such as the 'L1 or E5 band'. These frequency bands are allocated worldwide to GNSS on a primary basis and are shared with aeronautical radio navigation service (ARNS) systems.

Some of these systems also broadcast additional signals in other frequency bands located in the range 1215-1300 MHz, so-called L2 & E6 bands. These are also global GNSS bands but are allocated on a non-interference basis.

1 www.unoosa.org/oosa/en/ourwork/icg/icg.html
2 Not discussed in this report

GNSS INFRASTRUCTURE IS CONTINUOUSLY EVOLVING

Galileo and BeiDou plan to reach full operating capacity with their latest technology by 2020. In parallel GPS and GLONASS are engaged in modernisation efforts leading to better performance and higher interoperability.

GPS

The US is currently engaged in an ambitious GPS modernisation programme, which has deployed new satellites (GPS III) from the beginning of 2018. These satellites are the first to feature the new L1C signal, almost identical to its Galileo OS counterpart on E1. They will also broadcast the legacy L1 and the more recent L2C and L5 signals, resulting in the future availability of four civil GPS signals. The discontinuation of codeless and semi-codeless GPS access is expected to be completed by 2020 when civil users are encouraged to transition to the L2C signal.

More at: www.gps.gov

GLONASS

The first current generation GLONASS satellite, GLONASS-K, entered 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 ones, and also host a SAR transponder. The next generation constellation will be based upon GLONASS K2 and KM platforms, which are planned to be launched after 2020. These satellites feature improved clock stability, and new control, command, and ODTS technologies.

More at: www.glonass-iac.ru/en

BeiDou

The third generation BeiDou system (BDS-3) is currently being deployed with the goal of completing the constellation of 35 satellites by 2020 to provide global service. The final global system will transmit signals at the B1 (E1/L1), B2 (E5/L5) and B3 (~E6) frequencies. Sharing frequency bands and closely similar signal waveforms with GPS and Galileo, BDS-3 significantly contributes to the interoperable, multiple-GNSS world. BeiDou will operate the largest constellation of 35 satellites, including the regional system. This regional system will offer two services; a Wide-Area Differential Service and a Short Message Service. The former offers improved accuracy over the global offering, whilst the latter allows short, two-way communication for commercial purposes.

More at: en.chinabeidou.gov.cn

Galileo

After the declaration of Initial Services on 15 December 2016, Galileo continues its deployment and will reach its full operational capability (FOC) in 2020. As of end of August 2018, the constellation includes 26 satellites in orbit, of which 17 are fully operational. In addition to providing a high quality open service based on innovative signals[1] in the E1 and E5 bands, Galileo was also the first GNSS constellation to feature a SAR capability, including the provision of a return link to users in distress. Galileo also features other unique capabilities, such as the provision of Navigation Message Authentication (OS-NMA), and an encrypted navigation signal on E6, the Signal Authentication Service (SAS). OS-NMA and SAS represent 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 via the E6 frequency, used to broadcast high-accuracy augmentation messages.

More at: www.gsc-europa.eu

QZSS

The current four satellite system (three IGSO + one GEO) provides three satellite visibility at all times from locations in the Asia-Oceania regions. QZSS services will officially begin on 1 November 2018, 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 will provide 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 future Public Regulated Service, a Sub-metre Level Augmentation Service (SLAS), a Centimetre 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).

More at: qzss.go.jp/en

NavIC

NavIC-1L was successfully launched on 12 April 2018, to increase the NavIC constellation to seven operational satellites. NavIC covers India and a region extending 1,500 km (930 mi) around it, with plans for further coverage extension by increasing the number of satellites in the constellation from seven to eleven. 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).

More at: www.isro.gov.in/irnss-programme

1 The initial Galileo E1 BOC (1, 1) was used as the common baseline signal structure for EU/US cooperation discussions leading to the design and adoption of the current L1C (GPS) and E1b/c(Galileo).

THE MAJORITY OF SYSTEMS WILL REACH FOC WITH NEW SIGNALS IN FIVE YEARS

Ground segment updates

New signals and capabilities require not only to be implemented on satellites, but also to be monitored and controlled by the GNSS ground segment. Whilst Galileo and BeiDou are in their first generation, both GPS and GLONASS are modernising their control segments.

The GPS ground segment will be upgraded to the "Next Generation Control Segment" or OCX, which has undergone initial deployment in 2018.

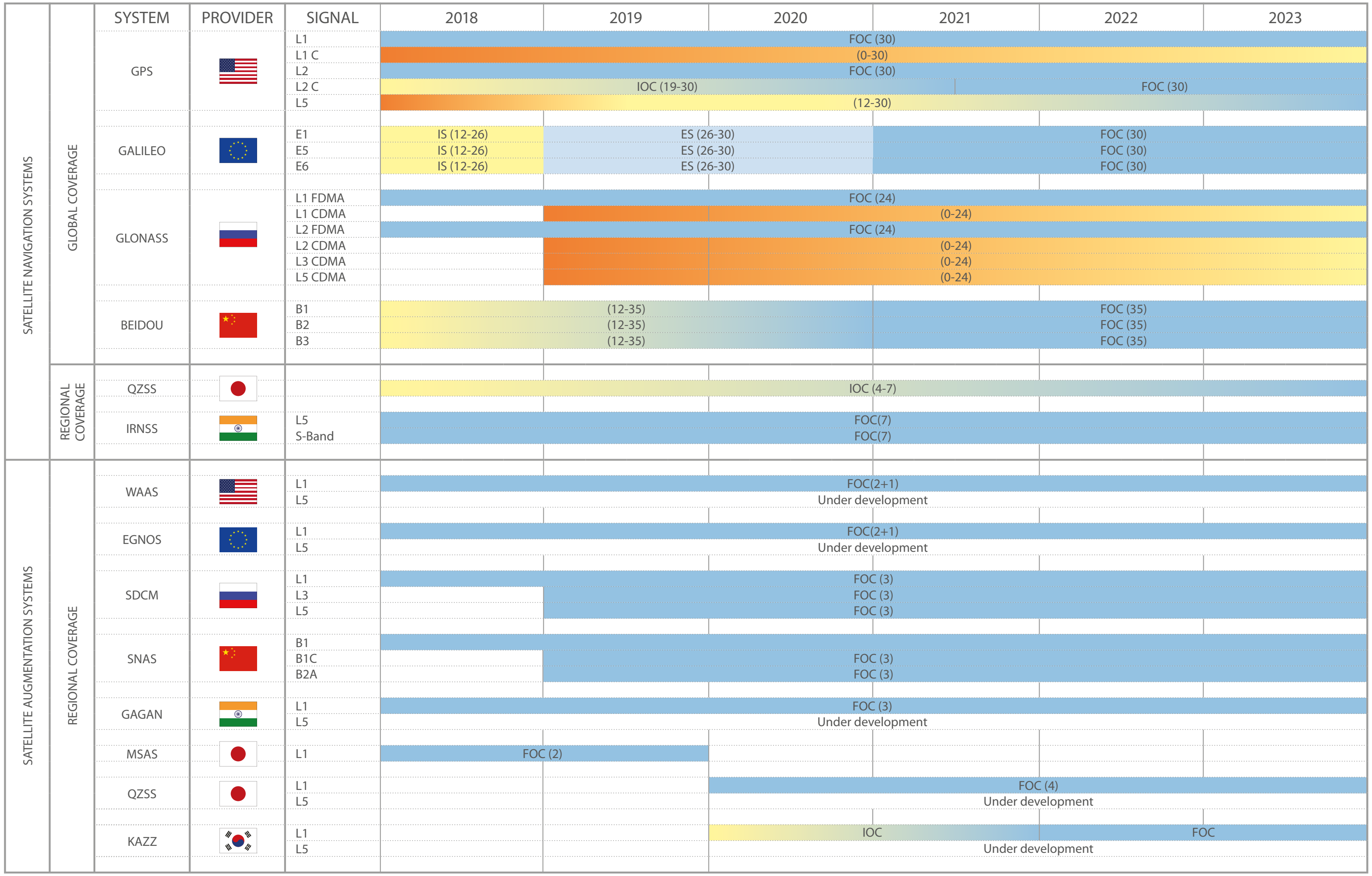
Similarly, new GLONASS capabilities are supported by a modernised ground segment with the objective to improve the system accuracy down to 0.6m Signal In Space Ranging Error (SISRE), and synchronization of GLONASS Timescale with UTC (SU) to less than 2ns.

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, status and number of satellites* are reported as follows:

Signal status
- No service
- Initial services
- Full services

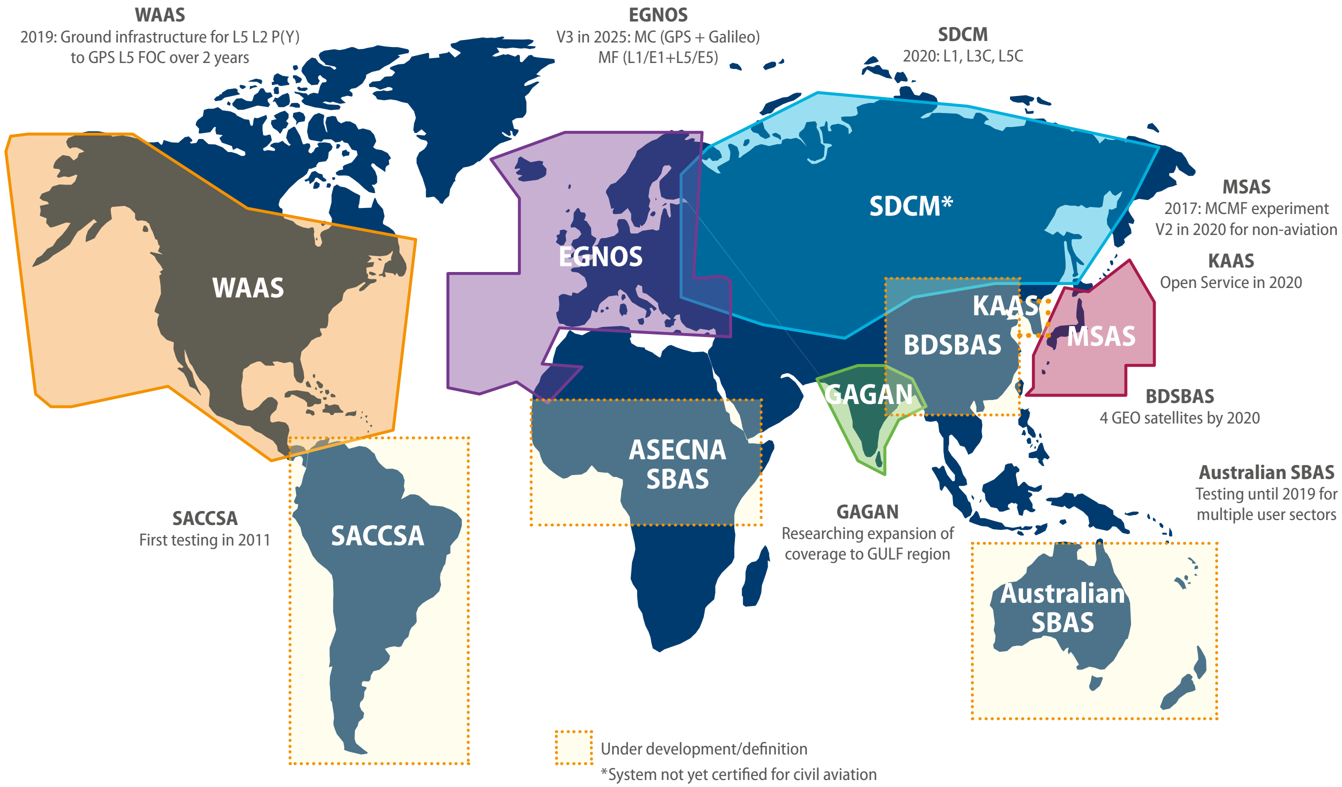
* The number in bracket indicates the number of satellites.



Disclaimer: Systems deployment plans based upon publicly available information as of July 2018.

PUBLICLY AVAILABLE AND SUBSCRIPTION BASED AUGMENTATION SOLUTIONS ENHANCE GNSS PERFORMANCE

SBAS INDICATIVE SERVICE AREAS



SBAS move to dual frequency and new sectors

Across the world SBAS systems are testing and implementing changes to support dual-frequency and, in many cases, multiple constellations.

In most cases L5/E5a is used as the second frequency signal, resulting in a dual frequency system. Some, such as MSAS and SCDM, intend to provide corrections for three frequencies.

At the same time as implementing systems meeting aviation LPV-200 (CAT-I) requirements, EGNOS, WAAS, QZSS, SCDM, and BDSBAS all have specific plans to support user sectors beyond aviation.

Sectors such as agriculture and maritime already enjoy benefits from SBAS in some applications, but future services will look to exploit the increased accuracy offered by dual frequency for more demanding applications.

Commercial augmentation services now use PPP and are moving towards 'V2.0', targeting the mass market

Commercial augmentation services have been mature for some time, but they are currently evolving to 'version 2.0'. Almost all global providers now offer PPP services to provide worldwide coverage. Regional Network Real Time Kinematic (N-RTK) augmentation service providers also increasingly incorporate a PPP service to provide a complete solution portfolio. Whilst established service providers embrace PPP to complete their offerings, newcomers benefit from its reduced infrastructure cost to propose novel services and facilitate emerging 'high-accuracy mass market' applications such as autonomous vehicles or augmented reality.

Whilst providing very high accuracy, existing services do not fully meet the needs of these emerging applications. For example the typical convergence or re-convergence time associated with PPP correction services will need to be improved to address automotive applications in urban environments, or to satisfy consumer expectations. Beyond this, such applications require integrity and robustness alongside high accuracy. Future services will have to work with receivers built on newly developed mass market premium chipsets, which support dual frequency and multi-constellation but are subject to power and hardware size constraints compared to traditional precision GNSS equipment. The move to address the mass market is resulting in increased availability and affordability of these services.

FOR USERS GNSS IS PART OF A 'SYSTEM OF SYSTEMS'

Synergies between systems

The future of space technologies relies on two words: 'integration' and 'fusion'.

Ubiquitous localization and timing, ubiquitous sensing, ubiquitous Connectivity, 3D digital modelling: these major technological trends are fuelling the fourth industrial revolution, characterized by the integration and fusion of different space and ground technologies and infrastructures; and a new, enhanced representation of our physical world.

These technologies will cause radical transformations of our society, such as those related to autonomous driving and to an extensive use of drones in commercial applications. With their fundamental role in localization and timing, remote sensing and communications, space technologies play an essential role in enabling such a future.

As a matter of example, in autonomous driving and autonomous drones operations (more generally, for whatever concerns 'Autonomous Things'), satellites not only provide ubiquitous communications, but also ubiquitous positioning and timing. Furthermore, Earth observation (remote sensing) merged with the IoT's ubiquitous sensing delivers an accurate, detailed and enhanced 3D representation of the world.

Thus, from mapping to farm management to environmental monitoring to autonomous mobile robotics, a wealth of innovative applications already benefit from the combined use of Europe's two flagship space programs: Galileo and Copernicus.

Many of these applications also depend on device connectivity; be it to receive assistance or augmentation data, to exchange with peers or to optimise the data flow between field and office, one always assumes that the device is connected. This is where, in areas without sufficient terrestrial networks coverage, the 'invisible' third pillar of the space applications, 'Communications' comes into play and provides the necessary connection that enables the seamless integration of our devices and information systems. Communication has always been a close cousin to positioning, as well as a complement. The current trend in this field is to propose very large or mega constellations of LEO satellites to provide affordable wideband connectivity worldwide. There are indeed several such plans, backed by major multinational companies:

Name	Proposed network size	Key backing organisations
ONEWEB	720 Initial, >2,000 target	Airbus, Virgin, Qualcomm, Intelsat, Bharti
STARLINK	4,425 initial, 12,000 target	SpaceX
BOEING	1,400-3,000	Boeing

Such networks of LEO satellites have the potential to play a similar role as 4G/5G telephony with respect to GNSS, i.e. a kind of symbiosis whereby GNSS can position the satellites, which in return can provide assistance and augmentation data and even complementary positioning signals.

Galileo and Copernicus for sustainable development

The UNOOSA (United Nations Office for Outer Space Affairs) and the GSA published a joint report in 2018 focusing on how E-GNSS and Copernicus support the UN's Sustainable Development Goals (SDGs).

From providing the maps needed to find the best locations for renewable energy infrastructure, to outlining the most fuel-efficient flight paths, optimising road transportation routes and infrastructure monitoring, applications using both GNSS and EO provide the answer to many societal challenges. Indeed the report highlighted that all of the United Nations' 17 Sustainable Development Goals were positively impacted by the combined use of E-GNSS and Copernicus, and of those 13 significantly benefit.

The report can be downloaded at: www.unoosa.org

UNITED NATIONS Office for Outer Space Affairs

European Global Navigation Satellite Systems Agency

Copernicus is the European system for monitoring the Earth and is coordinated and managed by the European Commission. The development of the observation infrastructure is performed under the aegis of the European Space Agency for the space component and by the European Environment Agency and EU countries for the in situ component.

It consists of a complex set of systems which collect data from multiple sources: earth observation satellites and in situ sensors such as ground stations, airborne sensors, and sea-borne sensors. It processes this data and provides users with reliable and up-to-date information through a set of services related to environmental and security issues.

The services address six thematic areas: land, marine, atmosphere, climate change, emergency management, and security. They support a wide range of applications, including environment protection, management of urban areas, regional and local planning, agriculture, forestry, fisheries, health, transport, climate change, sustainable development, civil protection, and tourism.

For more information see: www.copernicus.eu

Copernicus Europe's eyes on Earth

© ESA

ALL COMPONENTS OF GNSS RECEIVER ARE SUBJECT TO INTENSIVE DEVELOPMENT

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

Simultaneously, market pressures have exerted a pull towards increased accuracy, improved performance in difficult environments, and reduced time to first fix (TTFF). This simplified diagram presents the building blocks of a typical GNSS receiver alongside the 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 trend towards 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.

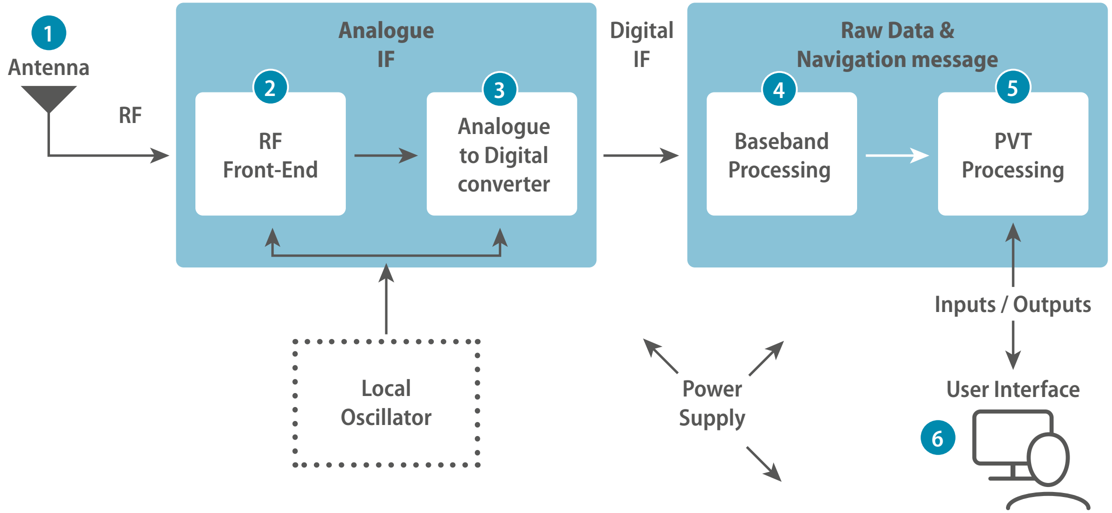
GNSS RECEIVER FUNCTIONAL BLOCK DIAGRAM

1. Antenna (+ preamplifier)

Receives, amplifies and band-pass filters GNSS signals.

Dimensions:

- Selectivity
- Noise factor
- Gain
- Radiation pattern
- Phase Centre
- Bandwidth
- Multi-frequency
- Multipath rejection
- Single or multiple antenna inputs
- Jamming mitigation



6. Input/ Output interfaces

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

2. RF down convertor

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
- Measurement rate
- Measurement noise (C/N0)
- Multipath immunity
- Signals/modulations processed
- Dynamics
- Interference cancellation
- Jamming mitigation

5. PVT (& Application) processing

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

Dimensions:

- Solution type (GNSS, Differential GNSS)
- Real Time Kinematic (RTK), Precise Point Positioning (PPP), …)
- Single or Multi constellation
- Update rate
- Latency

THE PVT COMPUTATION STRATEGY DICTATES THE ACCURACY BUT ALSO THE ROBUSTNESS OF THE SOLUTION

GNSS observations

GNSS receivers perform measurements on the incoming navigation signals to obtain direct observables which can be of two types, the code phase and the carrier phase. These are measures of the same physical quantity, the pseudorange, albeit with rather different characteristics.

CHARACTERISTICS OF GNSS OBSERVABLES

Observable	Typical precision	Ambiguity	Remarks
Code phase	1 m	1 code length (300 km for a C/A code duration of 1 ms)	The primary GNSS observable. Robust though limited in precision
Carrier phase	1 cm	1 carrier wavelength (19 cm at E1/L1)	Used for high-accuracy PVT estimation. Requires ambiguity resolution

These observables are contaminated by a number of errors which must be modelled, estimated or eliminated in order to compute an accurate PVT solution. When performed simultaneously on several frequencies, several satellites, or by several receivers, these observations can be linearly combined to form derived observables with particular interest for processing; for instance, this is the case of the "iono-free", the "widelane", or with several other combinations.

PVT processing strategies come in two groups - Code phase-based solutions that are robust but exhibit limited accuracy, and Carrier phase-based solutions that can potentially offer very high accuracy, but with greatly reduced robustness and at the cost of the resolution of the ambiguities.

Single Point Positioning

Single Point Positioning (SPP) is the default method. It is based on the use of code phase observables, either single frequency or dual frequency, possibly smoothed with carrier observations, and adjusted in a navigation filter, which is generally a least squares (LSQ), weighted least squares (WLSQ), Kalman or extended Kalman (EKF) filter. When only single frequency observables are available, a model (Klobuchar, NeQuick) is applied to account for ionospheric delays. Otherwise these are estimated or eliminated by an iono-free linear combination. The PVT accuracy depends on that of the received clock and ephemeris data (CED), and of the models used (all residual errors will propagate in the position solution). Since residual errors in SPP are larger than the signal wavelength, carrier phase observations can only be used for smoothing the solution.

Augmented GNSS

Whenever the performance achieved with SPP is insufficient, augmentation methods are used. They allow cancellation or precise modelling/estimation of the residual measurement errors.

- **Differential GNSS:** This method assumes a high spatial & temporal correlation of GNSS error components. It makes use of a reference receiver with known coordinates to determine the lump-sum of GNSS errors for visible satellites, and broadcasts this information. Users' GNSS positioning is improved by applying GNSS range correction as measured by the reference station.
- **RTK:** Real time Kinematic is the version of DGNSS that uses carrier phase observables instead of (carrier phase smoothed) code phase observables. It implies a successful resolution of the carrier phase ambiguities, which is all the more likely as multiple frequencies are used and the reference to receiver distance (baseline) remains small.
- **Network DGNSS/RTK:** These are versions of the above where a network of reference sites is used rather than just one, to extend the operational area and/or improve the redundancy of the solution.

Common to all three methods is the determination and use of a lump correction, and collectively they are known as 'observation space representation **(OSR)**' techniques. They provide a position solution **relative** to the reference station (network). The next two methods attempt to differentiate the different components of GNSS observations error – satellite clocks, orbits & signal biases, atmospheric delay/advance etc. Since the state of the GNSS error components is determined, this approach is called a 'state space representation' **(SSR)** technique.

- **SBAS:** This method uses a national or even continent-wide network of (dual frequency) reference stations to estimate corrections split into several components – including satellites orbits and clocks, and a real-time ionosphere model. These are broadcast (using a GNSS like signal) to receivers that reconstruct the correction in the observation domain and use a standard PVT filter.
- **PPP and PPP-AR:** This is the ultimate evolution of the SSR concept. All individual error components are estimated either at the network (worldwide) or at the receiver level. When these estimates are accurate enough to resolve the carrier phase ambiguities, precise unambiguous carrier phase estimates of the pseudoranges can be used and yield sub decimetre accuracy. This mode is referred to as PPP with ambiguity resolution (PPP-AR).

Whatever the augmentation strategy used, it implies relying on a (network of) reference station(s) and obtaining a solution relative to it. Furthermore, a real-time communication link is required. Finally, all carrier phase-based solutions require an estimation of the ambiguities, and continuous, cycle slip free measurements (thus excluding receiver duty cycling).

AFTER E1 AND E5 WHICH THIRD FREQUENCY WILL BE ADOPTED?

MAJOR GNSS POSITION COMPUTATION STRATEGIES

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

Dual frequency

Dual frequency receivers offer significant advantages over single frequency receivers in terms of achievable accuracy, but also in terms of improved resistance to jamming.

L5/E5a signals are located in frequency bands shared with ARNS, which are subject to increased regulatory protection (similar to L1/E1) and will hence be used for safety-critical transport applications, and will also be supported by SBAS (standards in development). L5/E5a will therefore be broadcast on more satellites than any other frequency. Additionally, signals on L5/E5a offer the advantages of a high chipping rate and of a higher received power than E1/L1 or L2.

This makes L5/E5a a natural choice for future dual frequency receivers, although currently there is a larger selection of GPS L2 capable receivers for legacy reasons.

After many years of use limited to professional or governmental users (mainly because of high cost), the first dual frequency chipset for the mass market was launched in 2017 (incorporating L1/E1 and L5/E5a). Several more are either available or announced in 2018.

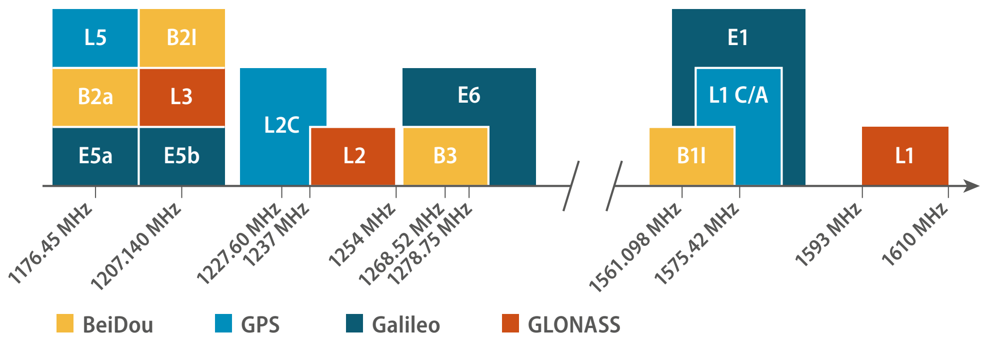
Triple frequency

While there are very compelling reasons to adopt dual frequency technology, the case for triple frequency is less clear and currently only high accuracy, professional grade receivers have adopted it. The main rationale behind triple frequency adoption is to improve the performance of the carrier phase ambiguity resolution algorithms, necessary for high-accuracy processing (RTK, Network RTK and PPP AR). These improvements are along three characteristics; the maximum separation from a reference station (for RTK and N-RTK), the reliability of the solution, and the time required to obtain and validate this solution.

When the selection of the two primary frequencies is dictated by their separation, their ARNS status and the sheer number of satellites that will use them, the choice of a third (or middle) frequency is far less obvious – Galileo and BeiDou make use of the E6 band, while GPS and GLONASS will continue to utilise the L2 band. Additionally, QZSS supports both E6 and L2C. Research papers typically show some advantages for E6 in terms of PVT processing, while some RF engineers favour L2 because the reduced frequency offset from E5 simplifies implementation.

An important and possibly decisive factor in favour of the E6 choice is the fact that Galileo and QZSS intend to use this frequency not only as a GNSS signal, but also as a data channel to broadcast (free) PPP augmentation messages, thus enabling the receivers to perform a PPP solution without requiring any other (external) communication channel.

GNSS FREQUENCIES IN THE L BAND



EVOLUTION IN SIGNAL PROCESSING OPENS NEW POSSIBILITIES FOR USERS

The inexorable march to high accuracy solutions from the surveying market in the 1990's, to all market segments today, has been enabled through the availability of more signals, increased processing power, and silicon miniaturisation.

Mass market dual frequency chips blur the lines with professional products

In less than ten years, the mass market chips have evolved from products capable of processing a single (L1 GPS) narrow band, low sample rate signal to dual wide band (Upper L Band - Full E1/ L1 - quad constellation + Partial Lower L Band), high sampling rates for the recently introduced multi-constellation dual frequency products. Such products feature two complete wideband RF front-ends, one for the upper L-band, one for the lower L-band (L5-E6), with separate RF inputs and separate external SAW filters to maximise performance.

For economies of scale a popular design is to use two identical front ends, albeit tuned to different frequencies. As the upper L-band covers 60MHz, but the full lower L-band almost 150 MHz, this strategy results in tuning choices for the lower frequencies (e.g. tuning on L5/E5a or on L2). As each individual signal does not require wide bandwidth or high sample rate, the functions of IF filters, frequency mapping to baseband, and down-sampling are performed in configurable digital hardware (pre-processors), before being fed to the GNSS baseband processor.

The discriminator stage, which yields the output of the correlation, is also evolving to perform additional accuracy and integrity functions. Owing to silicon density and new signals with a faster chipping rate (L5/E5), the direct and reflected components of the signal (multipath) can be identified and thus the direct signal tracked. For NLOS (non-line of sight) signals where only the reflection is received, the Doppler frequency can be established, and if not compatible with the user motion and the angle from the satellite, rejected. This approach also helps detect and reject spoofed signals.

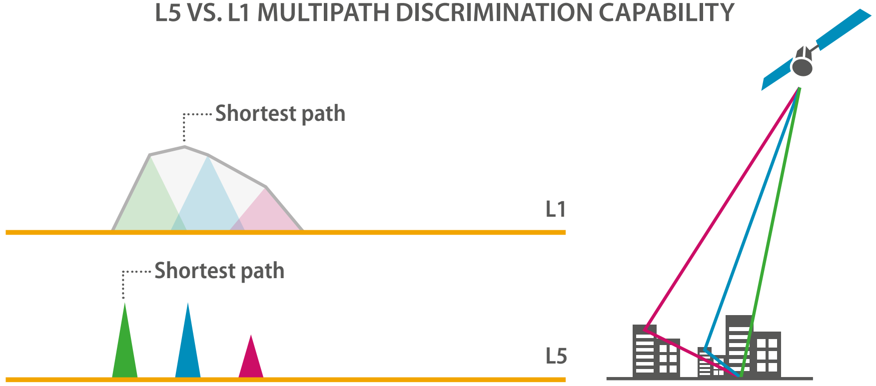
Such implementation (both front end and baseband) resembles that of dual frequency professional grade receivers of yesterday, with a trade-off between power consumption and processing. The very large quantities in which such chips are produced however allow access to state-of-the-art components technology (7 - 14 nanometre process), thus limiting the impact of the higher specifications on cost and power consumption for consumer devices, such as smartphones.

With regards to chips optimised for the IoT, such performance-driven design is not suitable and low energy designs are used instead. These are single frequency, narrow band, single or dual constellation products which can deliver a suitable performance level at minimal cost and energy per position fix.

Cutting edge developments improve carrier phase tracking

With the trend towards high-precision GNSS requiring carrier-phase solutions and ambiguity resolution, the signal processing must maintain phase lock in compromised situations. Techniques utilised include vector tracking (where the signal processing loops of all satellites are driven collectively using the error signals from the satellite channels that do have signal), and ultra-tight coupling (where the input signals from other sensors such as inertial or vehicle speed are also used to drive the signal tracking loops).

L5 VS. L1 MULTIPATH DISCRIMINATION CAPABILITY



Source: S.K. Moore, IEEE Spectrum

Professional designs implement trustworthiness features

Safety critical or high-precision receivers have prioritised performance over cost or power consumption for a long time. Highly intensive signal processing allows the implementation of direction of arrival processing, which provides orientation and anti-jamming/anti-spoofing. Receivers use full bandwidth processing to produce low noise, low multipath measurements. Furthermore, high precision receivers featuring hundreds of channels can dedicate a portion of the channels to tracking unwanted (multipath or spoofing) signals and eliminating them from the solution.

The demand for processing power is a multifaceted problem: the more satellites used in the solution, the more effective the processing becomes; however, the signals must still be subject to the full suite of processing (such as notch filters) to maintain the phase relationships of the signals if centimetre level accuracies are to be achieved.

While safety-critical receivers are slower in adopting new signals due to standardisation issues, they share a 'no compromise' approach on signal quality with high-precision products, and often adopt similar technical solutions, first proven in the high-precision world.

ANTENNA CAPABILITIES DRIVE RECEIVER PERFORMANCE

There is an increasing demand for high-performance, low-cost antennas. In the Mass Market Solutions section of this report we discuss the introduction of dual frequency into smartphones, together with access to raw measurements. These two changes could result in decimetre or centimetre accuracy, but this can only be achieved when the antenna delivers multi-frequency signal reception, and phase centre stability.

Meeting the demand for low-cost, high-performance antennas

GNSS antennas vary from tiny linear ceramic bars in phones, through active patch antennas in vehicles, to large sophisticated helix antennas for survey and reference station use, with choke rings and other large expensive precautions to minimise multipath. In all but the lowest-cost implementations, they include an LNA and a SAW filter.

For multiple frequency the complexity more than doubles, as the element itself must support the two frequencies, then the signal must be amplified, divided through a separate SAW filter for each band before amplification, and recombined to send down the coax to the GNSS receiver. This is illustrated in the diagram on the right. Here the red filter passes only the wanted lower L band and the blue filter passes only the wanted upper L band, while other unwanted signals such as radar or communication do not pass to the receiver. The challenge is to deliver this capability within the low-cost and space constraints typical to consumer devices. In the automotive world, dual-frequency patch antennas are the most likely solution.

Trading antenna cost against signal processing

Presently antennas in consumer equipment are optimised for cost rather than performance. As better sensitivity is achieved through signal processing, there is a tendency to use less effective antennas in combination with fewer analogue filters in the front end, and less attention to self-interference (e.g. phone clocks and peripherals).

With dual frequency, the low-cost linear ceramic antennas of the smartphone are unlikely to suffice, particularly if the centimetre level accuracy of PPP and RTK is to be achieved.

One approach would be the use of helical ceramic antennas, which are intrinsically wider band than patch antennas. Their profile is not as easy to integrate into devices, however, and would require careful design to avoid the antenna being subject to interference from the board.

Choosing which frequencies and mitigation techniques to support

When determining receiver specifications, the designer must choose which frequency bands will be supported and how. This is a multidimensional issue, as the antenna must match the range of frequencies selected, and suitably reject local interfering signals.

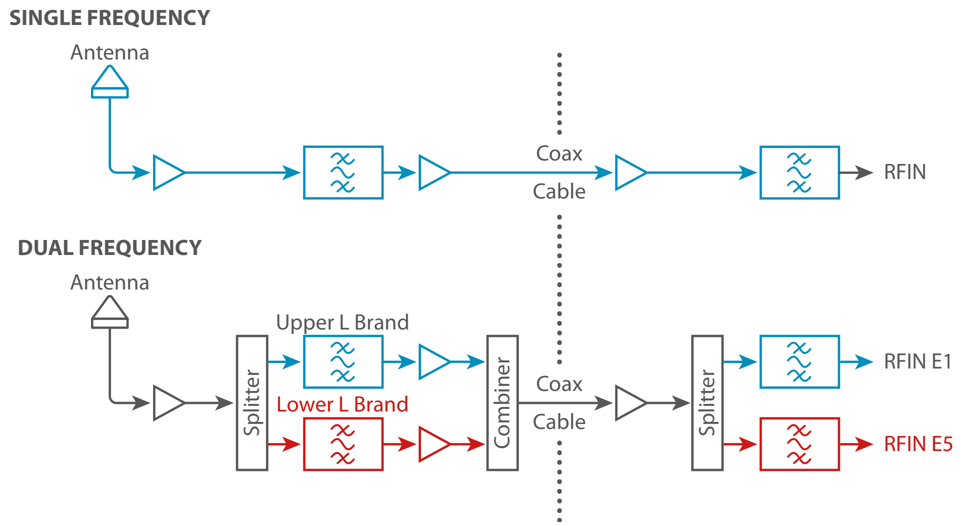
In applications that can support higher costs, the use of phased arrays can allow the mitigation of jamming signals and multipath by adjusting the response to steer beams and nulls to satellites and jammers respectively. These are not however appropriate for centimetre accuracy, as the antenna phase centre is variable.

Integration of positioning and communication antennas as an option for the future

Positioning and communications already show a high degree of overlap with tracking, assistance data, and the smartphone. Further integration is possible using ranging on LTE signals to add information to the position calculation, and this may have better indoor penetration than GNSS.

A shared receiving antenna may also be possible, but the issues associated with sharing with a transmitter would need to be assessed. The challenge is to avoid GNSS signals being blocked (jammed) by adjacent band LTE signals, or harmonics of lower LTE bands.

SINGLE VS. DUAL FREQUENCY GNSS RECEIVER RF FRONT END BLOCK DIAGRAM



MULTI-CONSTELLATION IS STANDARD IN TODAY'S RECEIVERS

Most of the current generation of receivers will still be within their product lifecycle as all constellations reach FOC status in 2020. As a result, manufacturers are now earnestly addressing all constellations, which has led to a dramatic increase in support for multi-constellation capabilities across the overall market.

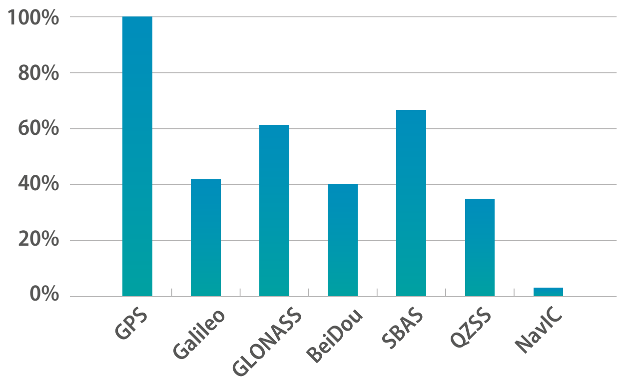
The vast majority of current receivers are multi-constellation, and the most popular way to provide multi-constellation support is to cover all constellations, which represents over 30% of receivers. The legacy use of single or dual GNSS (GPS/GPS+GLONASS) is reserved for applications with low performance requirements, or where regulations have not yet been updated to multi-constellation.

SBAS remains strongly supported, with almost 70% of receivers including the capability. Integration of QZSS has remained relatively stable, NavIC has begun to see adoption.

Multi-constellation has seen increasing adoption owing to the benefits it brings to receiver performance, particularly in environments with constrained sky view such as urban canyons. The range of benefits include:

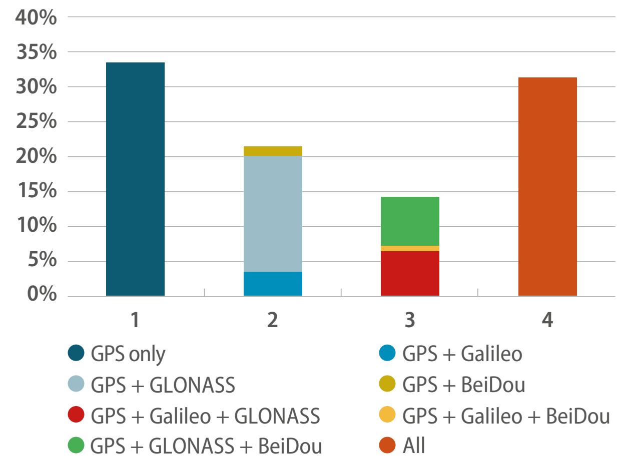
- **Increased availability*** - particularly in the aforementioned constrained environments, where shadowing would prevent a single constellation providing an adequate, or in some cases any, solution.
- **Increased accuracy*** - better geometry, and more signals which allow the receiver to reject compromised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

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 over 500 receivers, chipsets and modules currently available on the market. 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 III.*

MULTI-FREQUENCY IS COMMON IN HIGH PRECISION, BUT IS ENTERING OTHER DOMAINS

As new signals are becoming available from an ever larger number of satellites, receivers beyond traditional high-precision applications (for example commercial drones) are also demanding performance that can best be supported by multi-frequency. Simultaneously, multi-frequency receivers have been launched for the mass market, although have not yet seen wide-scale adoption.

This has resulted in a drop of nearly 10% in the production of receivers that are single-frequency only, over the last two years. The legacy configuration of L1/E1+L2 is still the most common multi-frequency combination, with over 20% of models (often linked with the use of only GPS or GPS + GLONASS). In the current transition period (E5a/L5 signals rapidly growing in numbers), several designs offer a configurable second frequency (either L2 or E5) that is selected by the customer when placing the order.

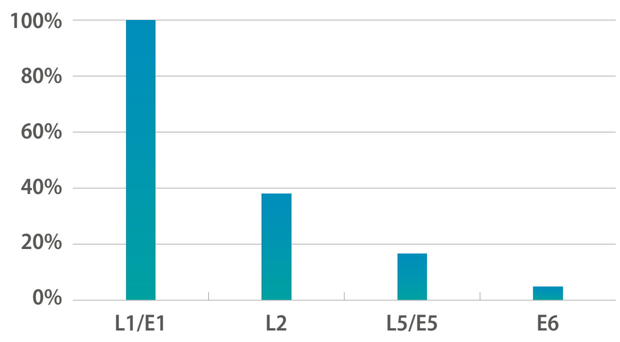
This results in a claimed "triple frequency" capability for such products, even though the actual use is dual frequency. As the data for this report's statistics are captured based on claimed capability (not on actual implemented configuration) they are represented as L1+L2+L5 in the chart below.

E6 is increasingly supported, having grown from 1% in 2016 to 5% today, but unlike E5/L5 remains limited to high-accuracy receivers.

Multi-frequency capabilities provide the following benefits:

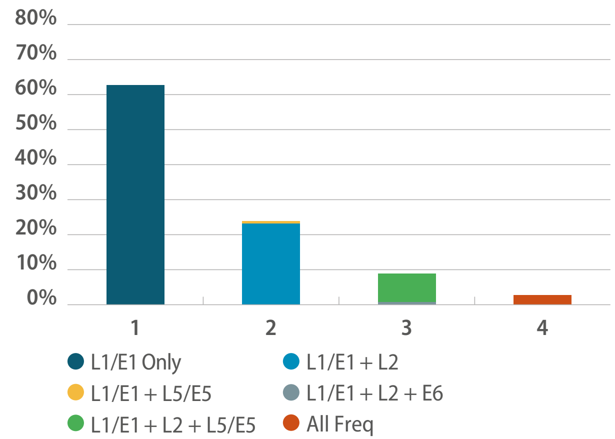
- **Improved accuracy*:**
  Multi-frequency receivers allow to estimate ionospheric delays. They are enabling differential techniques in practice, extending to triple-frequency allows integer ambiguity resolution in less time, which may be required in some applications.
- **Improved robustness*:**
  Frequency diversity provides some protection against simple jamming, especially if the receiver does not require L1 signals to initiate positioning.

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

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The GSA's independent analysis assesses the capabilities of over 500 receivers, chipsets and modules currently available on the market. 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 bands supported in manufacturers' offerings, rather than what is in use by end users.

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ANTI-JAMMING AND ANTI-SPOOFING DEVELOPMENT ACTIVITIES IN THE SPOTLIGHT

During the 1st Galileo User Assembly held in Madrid in November 2017, the importance of protecting against vulnerabilities was strongly highlighted as a common theme of user demands across applications sectors.

Jamming remains a challenge

At source, transmitted GNSS satellite signal power is equivalent to a 40-watt lightbulb. 20,000 km later, the signal arriving on Earth is very weak and extremely sensitive to interference and jamming. Even mW level interference in GNSS bands can disrupt GNSS reception up to several hundred metres, and cheap jammer devices available for a few euros on eBay aim to do this. Therefore defeating jamming impacts remains a key challenge. More sophisticated jammers do not only affect all GNSS frequencies but also jam mobile phone and Wi-Fi frequencies, thus denying almost all radio communications within range and making contingency measures more difficult.

Interference monitoring

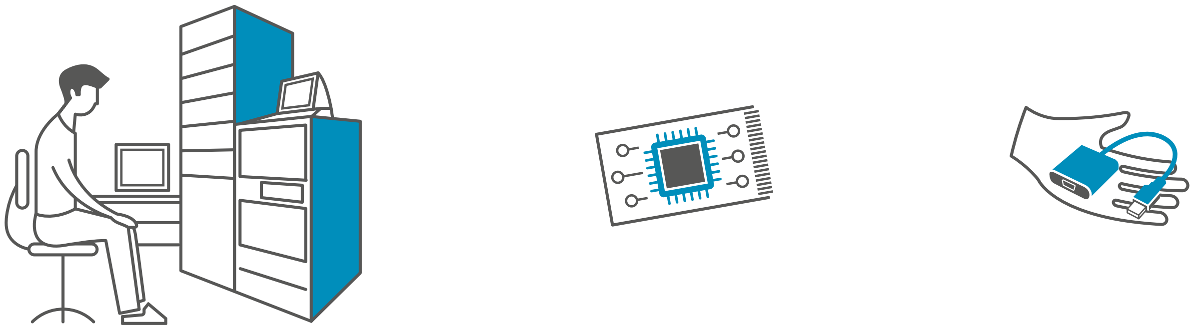
To handle the growth in use of such illegal jamming devices, many governments, together with research and academic institutes, are developing interference monitoring systems that could be deployed in critical or sensitive areas. Their purpose is to locate and identify jammer types as well as several other parameters (jamming duration, power, etc.). These systems help map and log jamming events, useful to the authorities, as well as being a potential value-added service for operators.

Moreover, in order to enhance GNSS receiver robustness, the EU's GNSS Radio Equipment Directive (RED -2014/53/EU) mandates that all receivers sold in the EU have a certain level of resistance to out-of-band interference.

Spoofing, the emerging threat

Spoofing uses GNSS-like signals to trick GNSS receivers into computing false positions, velocities and/or times. Even though GNSS signal specifications are open, spoofing has long been considered as difficult to implement and only possible for governmental organisations because considerable resources are needed to generate credible false signals. The relatively recent availability of low cost USRP (Universal Software Radio Peripheral) allows GNSS-like signals to be generated in software and then transmitted in GNSS bands. A simple €5 USB to VGA adapter can spoof L1 GPS signals using open source software available on the Internet.

GNSS SPOOFING CAPABLE DEVICES EVOLUTION COST



1989	2009	2013	2014	2016	2018
First commercial GPS simulator: STR2740 simulator	First low cost record, replay and GPS simulation	BladeRF SDR board able to simulate GNSS signal	HackRF one SDR board	LimeSDR-mini	A USB3 to VGA adapter able to replay GNSS signal
150,000 €	6,000 €	650 €	300 €	99 €	5 €

Spoofer Detection feature available in Javad products

The most recent innovations from JAVAD GNSS is isolating signals from spoofers, which cause receivers to provide incorrect position solutions if not protected against. The anti-spoofing option, which is available in all OEM boards too, defends against spoofers and provides the following information -

- Tracked: Signals that are successfully tracked.
- Used: Signals that are used in position calculation.
- Spoofed: With 864 channels and about 130,000 quick acquisition correlators in our TRIUMPH chip, we have resources to assign more than one channel to each satellite to find ALL signals that are transmitted with that GNSS satellite PRN code. If we detect more than one reasonable and consistent correlation peak for any PRN code, we know that we are being spoofed and can identify the spoofed signals.
- Jammed: Signals that are blocked by jammers.
- Replaced: The real signal is jammed and a fake signal is put on top of it.
- Faked: Signals that do not exist or real satellite is not visible.

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DIFFERENT TECHNIQUES ARE USED TO MITIGATE SIGNAL VULNERABILITIES

Jamming mitigation

Significant efforts were spent to overcome the jamming challenge, leading to the development of several technologies over the past few years.

The first approach is to implement filtering banks (in the time or frequency domains) at receiver RF Front End to excise the spurious signal. The efficiency of these techniques depends of the nature of the interferers and of the computation resources (and cost) dedicated to the filtering. CW (continuous wave) interferers can easily be removed by low-cost filtering such as Notch filters. Chirp signal jammers (technology widely found in in-car GNSS jammers), on the other hand, are more difficult to combat as these kinds of devices sweep a large frequency band.

Another approach is to avoid receiving the jammed signal at antenna level. Considering that the main threats are jamming devices emitting from the ground, the idea is to use antennas with patterns designed to receive only signals coming from the sky or able to control patterns to null signals coming from the direction where the jamming signal is detected. These technologies are costly however and used only in applications where GNSS is critical. Finally, although cancelling jamming is challenging, detecting it remains easier (using Automatic Gain Control monitoring, for instance).

The last solution is to design a system implementing contingency measures (see 'Increased PNT resilience' section on right) to be able to switch to a complementary solution in case GNSS-jamming is detected.

Spoofing mitigation

In response to this threat, the GNSS community developed several technologies to defeat GNSS spoofing both at receiver and system levels. These techniques encompass spoofing detection by monitoring signal metrics in order to detect flaws in the forged signal (signal power, time inconsistency, etc.), or the implementation of a built-in GNSS system defence solution such as the OS Navigation Message Authentication (OS-NMA) mechanism currently deployed by Galileo.

These latter techniques, however, mostly allow detection of spoofing only, not avoidance. The ultimate solution to fight against spoofing is to provide a way to avoid forging of a false signal. This is achievable by ciphering the whole GNSS signal such as in the Galileo Signal Authentication Service (SAS).

Increased PNT resilience

Increasing PNT resilience is on the agenda of many countries and industry players. The main areas currently investigated are:

- **INS** - An Inertial Navigation System is composed of motion sensors (accelerometer, gyrometer and magnetometer) allowing determination of the absolute movement of a platform. Using this information and knowledge of the last position, it is possible using dead reckoning to provide an estimation of position, velocity and time of the platform after spoofing or jamming detection.
- **SOP** - Signal of Opportunity positioning consists of using non-GNSS signals (AM/FM radio, cellular, digital television, Bluetooth, Wi-Fi, etc.) to complement GNSS and INS. It has been demonstrated that the fusion of SOP pseudoranges in a tightly coupled GNSS/SOP/INS system produces a better navigation solution than a traditional tightly coupled GNSS/INS framework.
- **Complementary systems** - Using other complementary PNT systems developed with distinct technologies such as eLoran or STL could improve resilience for some applications.

STRIKE3

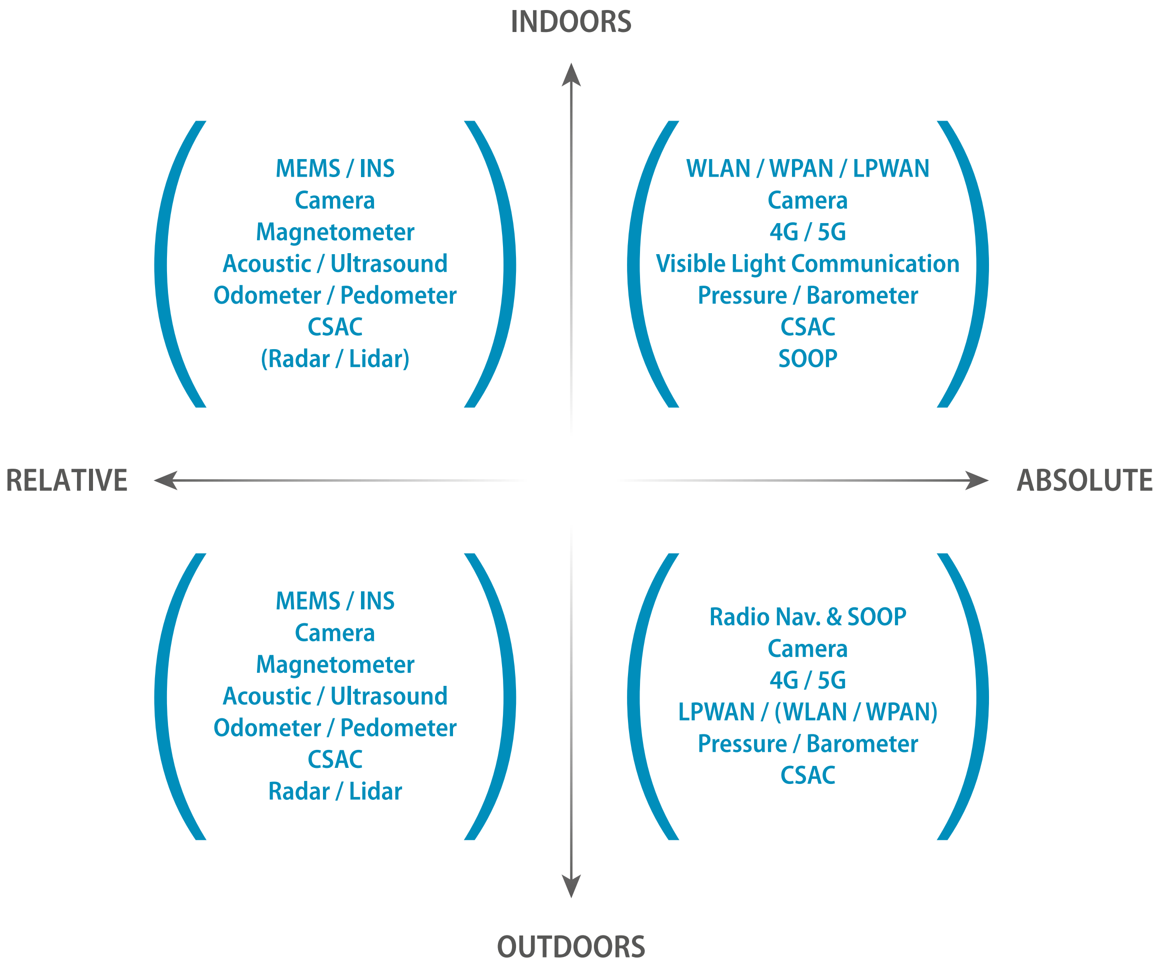
The use of GNSS is increasing in every aspect of our daily lives, requiring more and more constancy and predictability. STRIKE 3 aims to develop international standards for threat reporting and GNSS receiver testing. The process involves the development and deployment of an international GNSS interference monitoring network to capture the scale and dynamics of the problem, and requires international GNSS partners to develop, negotiate, promote and implement the standards as stated above. Ultimately the goal is suppression of international threats, by building a threat database based on central logging and analysis, which can be utilised in receiver testing. The project is already outputting statistics on the number of GNSS interference events detected at its various sites. Thousands of interference events have been detected per month highlighting the scale of the problem to be resolved.

More information can be found at: www.gnss-strike3.eu

COMPLEMENTARY TECHNOLOGIES TO GNSS SUPPORT ENVIRONMENT INDEPENDENT PNT

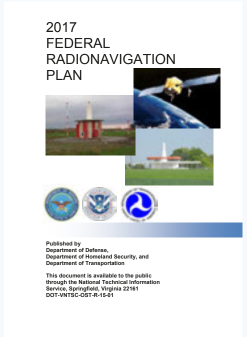
There are certain contexts where the usage of GNSS services is difficult or even impossible. Urban canyons are an example of the former, due to multipath effects and a reduction of the number of satellites in view. Tunnels, indoors or the underground are an example of the latter.

This gap in coverage or performance is not acceptable for many applications, and is addressed by using complementary technologies in the user PNT solution.

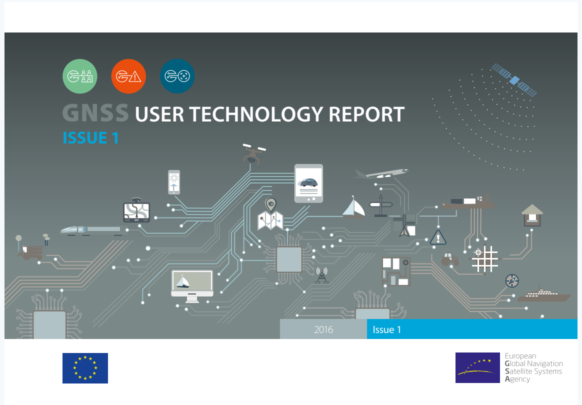


Useful Resources

The **European Radionavigation Plan (ERNP)** and its US counterpart, the **Federal Radionavigation Plan (FRP)** both discuss publicly provided alternative PNT systems, albeit as their name implies, focussing on radio-electrical means.



The GSA GNSS User Technology Reports (issue 1, 2016) includes a review of PNT technologies and sensors.



EUROPEAN GNSS DOWNSTREAM INDUSTRY LEADING THE WAY IN INNOVATION

Thanks to substantial investments in R&D, the European GNSS downstream industry is at the cutting edge of innovation in GNSS applications and services.

It holds a strong position in several domains: transport; high precision, timing and asset management; security and resilience.

Leveraging on Galileo differentiators, European actors keep developing user technology answering the needs of ubiquitous positioning, automation and secure positioning.

> "Europe has a fantastic opportunity to benefit from GNSS technology innovation in terms of quality of life, growth and jobs creation"

Gard Ueland, Chairman Galileo Services

Galileo Services

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

- Non-profit association founded in 2002
- Promotes the interest of EU, users and the European GNSS downstream industry
- Network* representing more than 180 companies
- Member companies active across the whole value chain and in all domains of applications
- Collaborates with national and European decision makers to foster development of the European downstream industry
- Enabling Europe to take a substantially larger share of the valuable global downstream market

** In 2009 Galileo Services and OREGIN (Organization of European GNSS equipment and service Industries) joined forces*

Page provided by Galileo Services.
For more information: www.galileo-services.org

H2020 AND FUNDAMENTAL ELEMENTS DRIVE INNOVATION OF THE GNSS APPLICATIONS AND TECHNOLOGY

GNSS downstream R&D programmes in Europe

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** focuses on supporting the 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 their services into devices, along with their eventual commercialisation.

The Fundamental Elements of European GNSS

With a budget of €111 million for the 2015 – 2020 timeframe, "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, Location Based Services (LBS), Agriculture, Surveying, Rail, Road, Maritime, Timing and Synchronisation and PRS.

The financial instruments for funding Fundamental Elements- supported activities include grants and tenders/procurements. Grants are the preferred financial instrument, with funding generally provided to beneficiaries for up to 70% of the total budget of the grant agreements (up to 100% for the tenders/procurements).

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

Horizon 2020

Horizon 2020 is the current EU Research and Innovation programme, offering nearly €80 billion in funding for the 2014 – 2020 period. European GNSS applications are part of the Space Theme, having synergies with topics on societal challenges. **Three E-GNSS calls were successfully concluded with a total budget of €100.9 million** (for statistics see next page).

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

A fourth call opens in October 2018 and runs until March 2019. Actions under the call are focused on two main types of activities; development of innovative Galileo and EGNOS-enabled applications in different market segments, and European GNSS awareness raising and capacity building.

The aim of the first type of activity is to support the market uptake of European GNSS in Europe and beyond. The innovative applications should leverage the differentiators of the EGNOS and Galileo systems, for example: multi-frequencies, high accuracy, authentication services, better accuracy for single-frequency users. Areas of innovation will include Galileo and EGNOS-enabled applications with commercial impact, that will foster green, safe and smart mobility, digitisation, and will also support societal resilience and contribute to the protection of the environment.

The second type of activity is dedicated to the development of E-GNSS competences. The actions will focus on raising awareness and providing opportunities for the creation of networks of industrial relationships. International cooperation is welcome as part of the action, when adding value and increasing the impact.

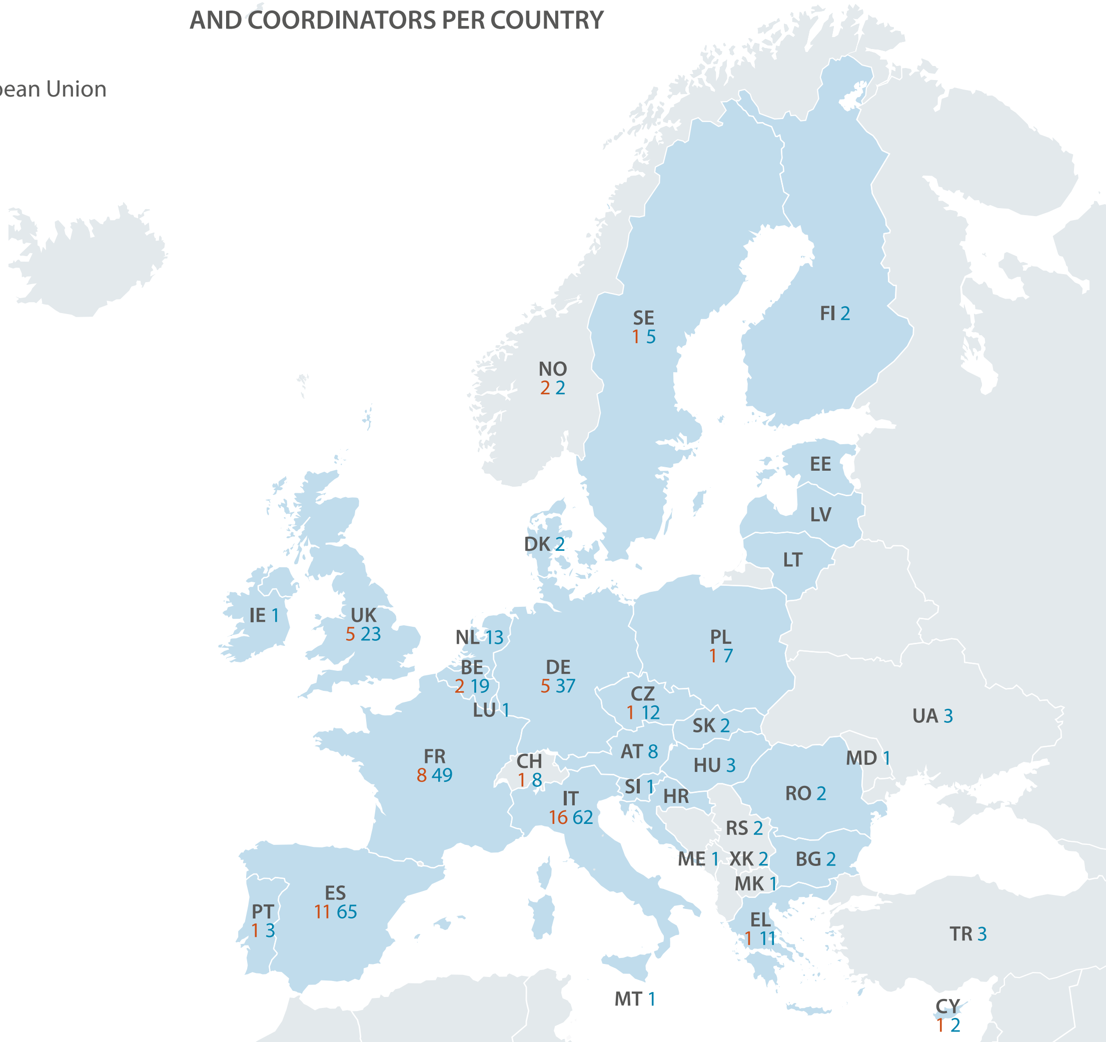
Overall, these activities will help to maximise the uptake of Galileo and EGNOS and to exploit the potential of the European GNSS industry, and also contribute to growth, competitiveness and jobs in this sector, while capturing public benefits.

More information about the upcoming call can be found here:
www.gsa.europa.eu/r-d/h2020/introduction

THREE H2020 E-GNSS CALLS RESULTED IN OUTSTANDING NUMBER OF PARTICIPATING ENTITIES

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	1
China	2
Egypt	1
Israel	1 and 2 coordinators
India	3
Japan	2
South Korea	2
Morocco	1
Malaysia	1
Palestine	1
Senegal	3
Togo	1
Thailand	2
Tunisia	1
Taiwan	2
United States of America	1
Vietnam	2

Three E-GNSS H2020 calls in a nutshell

Member States of the European Union:

- Entities from 24 Member States involved
- 53 coordinators and 333 partners involved in total

Non-EU countries:

- Entities from 20 countries involved
- Two coordinators and 39 partners involved in total

European Space Week 2018: Make space in your calendar

Mark your calendar for European Space Week 2018, and don't miss out on the leading European space programmes conference, connecting business, policy-makers, international experts and space application user communities, which will take place in Marseille, France, on 3-6 December 2018.

For more information visit the event website at: www.euspaceweek.eu

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.

Non-EU countries: CH Switzerland, **MK** Macedonia, **MD** Moldova, **NO** Norway, **RS** Serbia, **TR** Turkey, **UA** Ukraine, **XK** Kosovo.

MASS MARKET SOLUTIONS

AVAILABILITY AND POWER CONSUMPTION STILL RULE, BUT HIGH ACCURACY CAPABILITIES ARE APPEARING IN PREMIUM DEVICES

Characterisation of mass market solutions

Solutions presented in this chapter have mainly been developed for the following mass market applications:

- Location Based Services (LBS), covering smartphones/tablets, wearables and portable devices;
- Internet of Things (IoT) consisting of physical devices connected to the internet;
- Automotive solutions, covering tracking and navigation (as self-driving vehicles are safety-critical, they have been included in the next macrosegment);
- Drones, including implementations with basic navigation to those featuring high-fidelity cameras supporting First Person View (FPV).

Location Based Services still play the main role in the mass market. Customers require their smartphones, tablets, tracking devices, digital cameras, portable computers, fitness gear and other devices to use GNSS positioning. Taking into account the rate of introduction of new technologies, we might expect further development in:

- Artificial intelligence;
- Real-time tailor-made ecosystems;
- Hyper mobility (e.g. medical-grade mobile devices linked to digital healthcare platforms);
- Shared responsibility (e.g. accountability for decisions taken).

To achieve the required performance in existing LBS devices, other technologies are frequently adopted to complement GNSS. These include assistance data derived from:

- Cellular network positioning;
- WLAN (Wireless Local Area Network) or Wi-Fi positioning;
- Wireless Personal Area Network (WPAN);
- Low Power Wide Area Network (LPWAN);
- RFID;
- Ultra-Wide Band (UWB);
- MEMS gyros and accelerometers.

Key performance parameters for mass market

While in the report for previous years the key performance parameters were defined as:

- Availability;
- Power consumption;
- TTFF;
- Indoor penetration.

Recent developments, especially in consumer drones, mapping and GIS and mHealth, have increased the importance of:

- Accuracy;
- Continuity;
- Robustness and Integrity.

A number of applications shift from 'on demand' to continuous location information, imposing more stringent requirements on a wider variety of KPPs.

MASS MARKET KEY PERFORMANCE PARAMETERS

Key Performance Parameter (KPP)*	Mass Market Solutions
Availability	● High
Accuracy	● High
Continuity	● High
Integrity	● Medium
Robustness	● High
Indoor penetration	● High
Time To First Fix (TTFF)	● High
Latency	● Low
Power consumption	● High

● Low priority ● Medium priority ● High priority

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

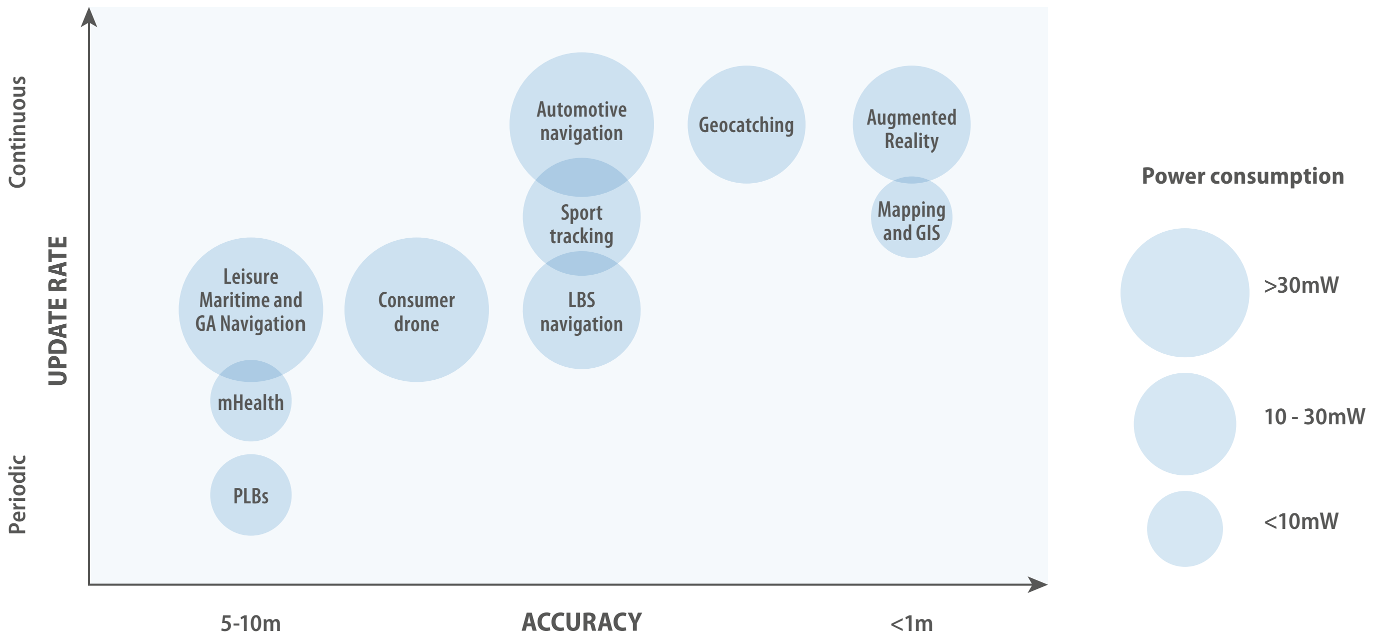
CONSUMERS PLACE DIVERSE DEMANDS ON GNSS

Manufacturers strive to achieve economies of scale in production of their hardware, but users expect different levels of performance across applications, and a 'one-size-fits-all' approach means that the smartphone chipset is not quite the solution to every situation. Instead manufacturers combine their chips in different ways, and utilise different techniques at the firmware/software level to optimise performance. The chart below shows how the key performance parameters (addressable by GNSS) are tuned in devices targeting different consumer applications.

The figure charts the relative accuracy (x-axis), update rate (y-axis), and power consumption (bubble size) of GNSS chipsets used in mass market applications today.

- For accuracy, the performance ranges from 5-10 m to sub-metre, with augmented reality and mapping/GIS demanding decimetre accuracy.
- For update rate, the performance ranges from periodic autonomous update (allowing the receiver to hibernate fully between updates), to continuous tracking with no possibility to reduce duty-cycle.
- Power consumption ranges from <10 mW, as seen in some IoT receivers, to >30 mW, which is effectively supported through an external power supply.

RELATIVE PERFORMANCE OF MASS MARKET RECEIVERS



THE MASS MARKET SUPPLY CHAIN REMAINS STABLE

Mass market is no longer confined to LBS using smartphones

Whilst this market is still growing, new areas are now **established** (automotive, wearables and the Internet of Things, etc.) and **emerging** ones (enterprise applications, social networking, sports & games, and quickly developing consumer drones) are also influencing technology development. There is now great potential for applications connecting diverse technologies – OBD (On Board Diagnostics), inertial navigation, Bluetooth, low-energy beacons, etc.

The main players in the LBS GNSS market are components manufacturers, device integrators and vendors, service & content providers, and application developers/retailers and stores.

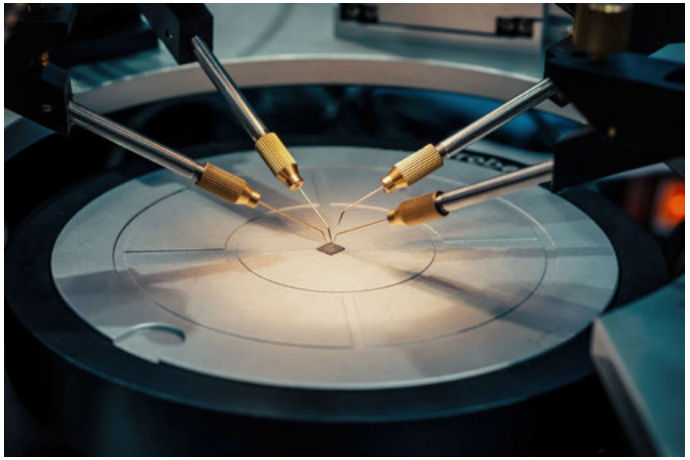
From a geographical point of view, non-EU players are dominant in the mass market. North American companies are leading the chipset market, and Asian companies are ahead in terms of handset revenues.

Significant mass market characteristics are a focus of manufacturers in different segments – undoubted dominance of Qualcomm, Broadcom and MediaTek in the **smartphone** market, and a focus of u-blox and STMicroelectronics in the **automotive** and **IoT** segments. Sony Semiconductor Solutions Corporation is a new player in wearables alongside Qualcomm, Broadcom, Mediatek and u-blox entering the market with super low-power solutions. Intel continues to lead in laptops and is entering into smartphones and IoT.

In drone technology evolution, the ubiquity of smartphone chipsets has supported the exponential growth of consumer drones. The PNT performance demanded by drones, however, is accelerating the drive for accuracy and integrity (to support geofencing) in high volume chipsets.

Companies focus on success in innovation and implementation, which are beyond metrics like market share. They are also covering slightly different parts of the solution, with Qualcomm or Mediatek dominating in integrating mobile connectivity and GNSS, and Broadcom focusing on GNSS sensor hubs.

GNSS IoT modules have been manufactured both by 'established receiver makers' such as Qualcomm, Intel, and u-blox, and companies focusing on module manufacturing like Quectel and SIMcom.



Leading manufacturers, shown in the table below have not changed since issue 1 of this report. Despite this stability in global chipset supply leadership, emerging technologies are increasingly allowing start-ups to find their niche in the market.

LEADING COMPONENTS MANUFACTURERS

BROADCOM	North America	www.broadcom.com
INFINEON	Europe	www.infineon.com
INTEL	North America	www.intel.com
MEDIATEK	Asia-Pacific	www.mediatek.com
QUALCOMM	North America	www.qualcomm.com
SAMSUNG	Asia-Pacific	www.samsung.com
SPREADTRUM	Asia-Pacific	www.spreadtrum.com
STMICROELECTRONICS	Europe	www.st.com
U-BLOX	Europe	www.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.

MULTI-CONSTELLATION IS NOW STANDARD FOR MASS MARKET RECEIVERS, IS MULTI-FREQUENCY NEXT?

By 2018 multi-constellation has become standard, and multi-frequency chipsets are available in volume production for the mass market. This is beginning to create a divide between premium chipsets, where performance can differentiate products, and low-cost chipsets, where cost and power consumption dominate.

Multi-constellation adoption

As FOC for all GNSS constellations is within the lifecycle of current products, multi-constellation (MC) capabilities (and the ability to utilise them selectively in energy saving modes) has become the norm for high-volume devices.

In the mass market world, most applications must operate in environments with constrained sky view, like urban canyons and indoors. Whilst the communications technology inherent in such devices are complementary, GNSS still provides the core solution, and simultaneous MC processing offers improved availability and achieved accuracy (compromised signals can be rejected from the solution). As new ASICs are increasingly expensive to design and build, products differentiate their capabilities through firmware configuration at the module and device level, rather than hardware.

Adoption of Galileo, BeiDou, GLONASS, and QZSS have all increased since the previous issue of the Technology Report. Support for all constellations is now the most common approach.

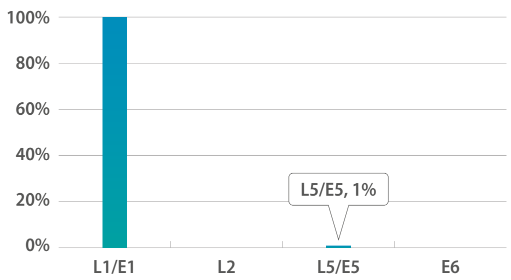
Processing load and resultant energy consumption remain issues which developers must balance against performance, and in practice low-cost devices may utilise architectures that operate constellation-specific functionality. This leads to a divide between premium, high-performance, and low-cost, low-power receivers within the mass market.

Multi-frequency

Whilst nearly all current devices utilise L1/E1 signals only, 2017 saw the introduction of premium mass market chipsets which incorporate L5/E5a signals. Smartphones incorporating these chipsets were first launched in June 2018, with many others expected to follow.

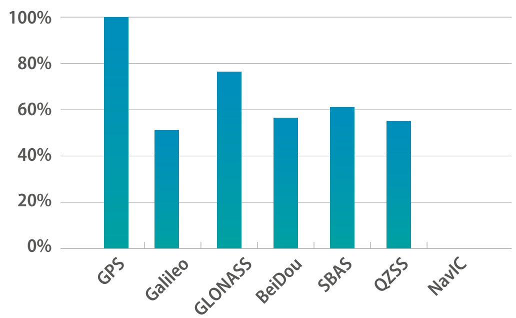
Dual frequency receivers offer improved accuracy and robustness, and access to high precision techniques (PPP and RTK) currently only common in more specialised receivers, blurring the line with professional products.

Frequency capability of GNSS receivers[1]



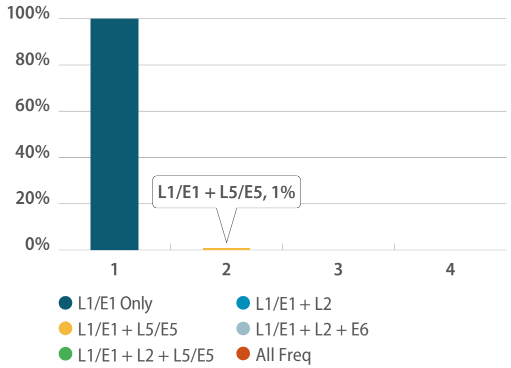
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



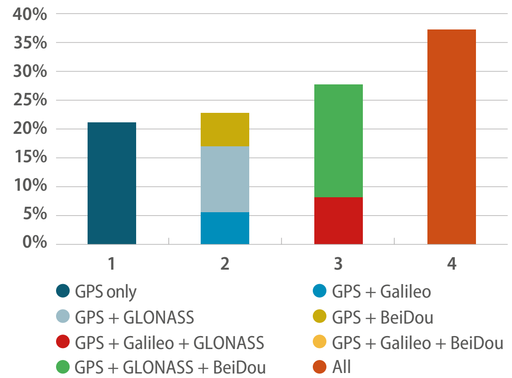
[2] shows the percentage of receivers capable of tracking each constellation

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 GNSS 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.

MASS MARKET CHIPSETS VARY BETWEEN LBS, IOT, DRONES AND AUTOMOTIVE

TYPICAL STATE-OF-THE-ART RECEIVER SPECIFICATIONS FOR THE MASS MARKET SEGMENT

Features		LBS	IoT	Drones*	Automotive*
Dimensions		15 x 15 x 3 mm	3 x 3.2 x 0.36 mm	10 x 10 x 1.5 mm	10 x 10 x 2 mm
Weight		1.6 g	0.5 g	1 g	1g
Operating temperature range		-40 to +85°C	-40 to +85°C	-40 to +85°C	-40 to +105°C
Power supply		2.5 - 3.6 V	1.4 - 3.6 V	2.7 - 3.6 V	3.0 - 3.6 V
Current consumption	Hibernate	10 mA	10 µA	30 µA	30 µA
	Acquisition	100 mA	28 mA	28 mA	10 mA
	Tracking	28 mA	3-8 mA	21 mA	28 mA
Number of channels		80	72	72	16
Number of frequencies		1**	1	1	1**
Time-To-First-Fix	Cold start	26 s	26 s	<40 s	<40 s
	Hot start	1 s	1 s	1 s	1s
	Aided starts	2 s	2s	3 s	2.5 s
Sensitivity	Tracking	–167 dBm	–160 dBm	–167 dBm	-159 dBm
	Acquisition	–160 dBm	–160 dBm	–146 dBm	-146 dBm
	Cold start	–148 dBm	–148 dBm	–145 dBm	146 dBm
	Hot start	–156 dBm	–157 dBm	–155 dBm	-155 dBm
Max navigation update rate		5 Hz	4Hz	18Hz	30Hz
Velocity accuracy		0.05 m/s	0.2-0.05 m/s	0.05 m/s	0.03 m/s
Horizontal position accuracy	Autonomous	2.5m	1.2m	2.5m	2.5m
	SBAS	2m	N/A	N/A	2m
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	<4g	N/A	<4g	<4g
	Altitude	50,000 m	N/A	50,000 m	50,000 m
	Velocity	500 m/s	N/A	300 m/s	300 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 but are not yet typical.*

Mass market receivers have evolved rapidly in recent years. LBS devices remain primarily E1/L1 and support multiple constellations, but dual-frequency receivers have now been launched. For IoT, manufacturers have developed receivers with less than 3 mA continuous tracking power consumption. Consumer Drone offerings utilise low-cost GNSS receivers designed for LBS devices. Some of the current generation of consumer automotive modules incorporate dual frequency. As self-driving cars reach the market and the GNSS function becomes mission critical, new chipset generations will evolve to meet the safety requirements of ISO 26262, ASIL and will be reported in the Transport safety- and liability-critical solutions section.

In the past, constellation support differentiated low-cost and premium **LBS** receivers; today the differentiator is frequencies. The majority will continue to utilise only L1/E1 and may claim multi-constellation support, but favour single-constellation operation to keep power consumption low. The latest generation of receivers however includes those with L1/E1 and L5/E5a, and target premium smartphones that seek to deliver applications such as augmented reality.

IoT receivers now frequently incorporate multi-constellation, but may process them selectively to save power. Continued development of power saving modes of operation now offers reduced sensitivity, update rate, and disabling SBAS tracking in return for significantly reduced power consumption. Duty-cycling remains the favoured approach to reduce power consumption, and A-GNSS remains integral to delivering the required fast TTFF.

Drone receivers are typically supplied to drone manufacturers as a module incorporating MEMS accelerometers/gyros along with other functions. Sharing common features with LBS receivers, a typical receiver will provide multi-constellation solutions. Consumer drones' mission time is constrained by propulsion, meaning that power consumption of the GNSS module is a lower concern than in LBS.

Automotive receivers are less constrained by power consumption than other mass market chipsets. As a result they do not sacrifice sensitivity by duty-cycling, can track all satellites in the sky including SBAS, and are also starting to adopt multi-frequency. They also operate with external active antennas, which provide improved signal strength. Tightly coupling satellite and MEMS based inertial measurements allows high-rate position output, even in compromised scenarios.

DUAL FREQUENCY ENTERS HIGH-VOLUME RECEIVERS

In 2017 and 2018 manufacturers launched multi-frequency receivers for the mass market. These architectures open the door to high-precision techniques, which could result in decimetre accuracy in high-volume receivers.

New receivers provide dual frequency

In September 2017 Broadcom launched their BCM47755, the first dual-frequency (DF) chipset aimed at the smartphone market. In February 2018 u-blox launched their F9 chip, and STM launched their latest Teseo receiver, both targeting automotive applications and supporting L1 + L2 or L1 + L5 frequencies. Intel presented a dual frequency prototype in early 2018, and Qualcomm demonstrated their Snapdragon X24 LTE, supporting concurrent multi-constellation, multi-frequency GNSS at the Mobile World Congress (Barcelona) in February 2018.

Dual frequency addresses consumer demand for accuracy

User demand for more stringent horizontal and vertical accuracy, for example in applications such as mHealth, augmented reality, and the migration of mapping GIS to high volume devices[1], has led accuracy requirements to tighten from metre to decimetre level.

Delivering high accuracy requires **carrier phase positioning with ambiguity resolution**. Dual frequency measurements enable direct **ionosphere** delay estimation, and use of techniques such as **wide laning** for quasi instantaneous, "on the fly" ambiguity resolution. In urban environments, multi-constellation is also needed to achieve an accurate solution (in order to provide good dilution of precision, residuals for Fault Detection and Elimination (FDE), and sufficient multipath-free measurements).

Promising potential

In January 2018 the GPS World magazine published updated results from Trimble's investigation into "Positioning with Android: GNSS observables"[2]. Using a proprietary positioning engine, they were able to demonstrate the possibility of centimetre level accuracy using the BCM47755 chipset and antenna in ideal conditions. Compared to existing professional GNSS devices the convergence time (for ambiguity resolution) was compromised, however the study provided a glimpse of future possibilities for consumer receivers.

Similarly Novatel tested the Teseo APP (Automotive Precise Positioning) and Teseo V chipsets with their high-precision positioning engine and correction services, in order to demonstrate significant reductions in position errors utilising the dual-frequency capabilities of the chipset[3].

These results show that sub-metre accuracy is possible with the right conditions. As techniques evolve to address the limitations of mass market hardware, such performance will become commonplace. This will underpin a suite of new applications like augmented reality.

Remaining challenges solved with L1/E1 and L5/E5a for the mass market?

There are challenges remaining to be addressed in terms of delivering sufficient accuracy, such as development of low-cost antennas with good phase centre stability and improved duty cycling to reduce power consumption[2]. The combination of L1/E1 and L5/E5a can unlock performance gains through higher chipping rates, but these require an increase in receiver power that must be kept minimal.

Will next gen smartphones be classified based on the quality of their GNSS?

Smartphones with dual-frequency (L1/E1 + L5/E5) GNSS receivers have recently hit the market (the first being Xiaomi's Mi 8), and they stand out thanks to their unprecedented location accuracy. These smartphones will be using the Broadcom BCM47755 Dual-Frequency GNSS receiver chip, introduced in 2017 and the first one ever designed and produced for the mass market.

It uses the more advanced L5/E5 signals available from Galileo and from the latest GPS satellites, in addition to traditional L1/E1 signals. The BCM47755 is capable of producing fixes with thirty-centimetre accuracy, and also mitigates urban multipath induced errors in a much more reliable way than legacy GNSS receivers.

As these dual frequency GNSS smartphones become available in the market, customers will start experiencing the enhanced location accuracy. These new smartphones will also showcase Galileo's critical contribution to the accuracy, because if Galileo signals were not available, then more than half of the L5/E5 signals would vanish, and the chip would fall back to traditional L1/E1 performance.

We believe dual-frequency GNSS will soon become a performance differentiation factor, so much so that next generation smartphones will be classified based on the quality of their GNSS receiver. Customers will consider the GNSS technology in the smartphone as one of the factors when selecting the device they want to purchase. This demand will push the smartphone OEMs to make the dual-frequency GNSS feature visible to their customers... maybe showing a unique location icon on the top bar of the display whenever dual-frequency is used. A clear indication of the GNSS quality. Time will tell.

Testimonial provided by the company

1 Report on location-based services user needs and requirements.
2 http://gpsworld.com/positioning-with-android-gnss-observables/
3 https://www.gsa.europa.eu/sites/default/files/expo/luis_serrano_stm.pdf

ACCESS TO RAW MEASUREMENTS OPENS NEW POSSIBILITIES FOR APP DEVELOPERS AND USERS

Google made GNSS raw measurements available on Android Nougat and higher in 2016. Since then third party developers can access carrier and code measurements, as well as decoded navigation messages in a growing number of consumer receivers. This opens the door for the use of advanced GNSS processing techniques that have previously been restricted to professional receivers. Several application areas stand to profit from the potential increase in accuracy, such as augmented reality, location based advertising, mobile health, and asset management. Depending on the device, the API can provide access to navigation messages, carrier phase measurements and to parameters needed to generate pseudoranges.

FOUR MAIN AREAS OF INNOVATION ENABLED BY GNSS ANDROID RAW MEASUREMENTS

Scientific use and research and development

- As raw measurements are avaible on an open source platform, the barrier to entry for development of novel hardware and software solutions is dramatically reduced.
- Scientific users can use observations for testing harware and new post processing algorithms.

Increased accuracy

- Subject to hardware limitations, access to raw measurements means a developer can employ advanced positioning techniques and create a solution currently only available in professional receivers.
- It results in a technological push to develop new applications.

Integrity and Robustness

- Access to raw measurements allows applications to include unique interference detection and elimination techniques.
- SBAS corrections can be incorporated without the need for additional equipment.
- Raw measurements allow applications to compare solutions between constellations and provide spoofing protection, or even use genuine system features such as OS-NMA.

Testing, performance monitoring and education

- Researchers have already been able to use raw measurements to monitor performance of solutions from individual constellations, and compare with other constellations as well as with combined solutions.
- The educational dimension of access to raw measurements in a device used by everyone on everyday basis is not negligible too.

Android raw measurements task force

Launched in June 2017 and coordinated by the European GNSS Agency (GSA), the **GNSS Android Raw Measurements Task Force** aims to share knowledge and expertise on Android raw measurements and their use, including their potential for high accuracy positioning techniques relevant to mass market applications. The Task Force includes GNSS experts, scientists and GNSS market players, all of whom are dedicated to promoting a wider use of these raw measurements.

As a first output of this joint endeavour, the Task Force has published a "White Paper on using GNSS Raw Measurements on Android devices". The White Paper provides an insight into the topic, including guidance on how to derive pseudoranges from the raw measurements, first testing results using various positioning techniques, practical tips, and an outlook on its use.

More information, including upcoming workshops, can be found at: www.gsa.europa.eu/gnss-raw-measurements-task-force

The White Paper can be downloaded at www.gsa.europa.eu

TESTING CAMPAIGN OF ANDROID SMARTPHONES DEMONSTRATES GALILEO ADDED VALUE

With the declaration of Initial Services in December 2016 Galileo became operational, providing highly accurate navigation signals around the world. The number of satellites in view made it feasible to use Galileo not only for testing proposes, but also for effective use in user devices such as smartphones.

To facilitate the optimal integration of Galileo signals in smartphones, the GSA launched a test campaign of such devices to assess their implementation, the user benefits stemming from it (in terms of location accuracy and availability), and to provide feedback to the manufacturers.

Thanks to Google's 2016 announcement that raw GNSS chipset data could be accessed from Android 7 devices, users can now process the same raw data that GNSS chipsets use to compute PVT solutions. The access to the GNSS raw data brought the opportunity to assess relative constellation performance, i.e. the benefit of using each different GNSS constellation. Moreover the quality of the different GNSS signals, such as Galileo signals, could be assessed.

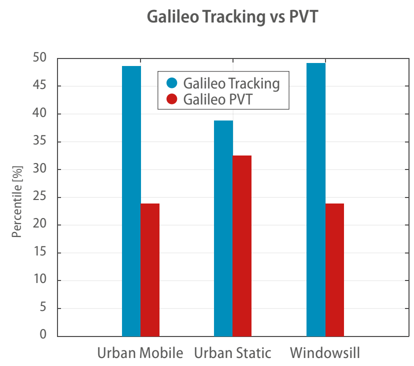
Thus, the testing campaign aimed to assess the real user experience, taking into account not only the GNSS chipset, but all the elements in a smartphone influencing the quality of the location, such as the integration of sensors, the antenna and the power saving techniques. The campaign also gave the opportunity to provide feedback to the GNSS chipset manufactures in order to optimise their multi-GNSS implementation and in particular, the use of Galileo.

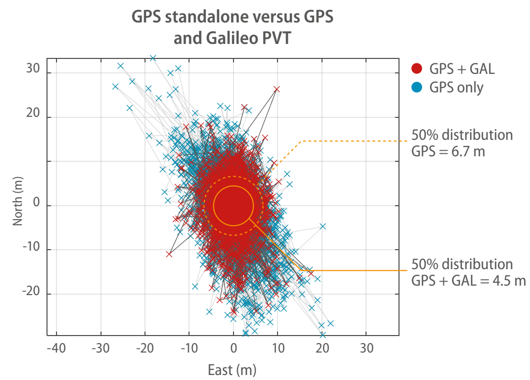
The test campaign is based on record and replay signals in order to assess the different devices under the same conditions. Moreover a small number of live test cases are also included, to assess the impact of the assisted GNSS data.

The main monitored figures of merit are:

- **Galileo Tracking Availability** – Quantifying the receiver ability to track satellites. It computes the percentage of time that the receiver is providing measurements for a particular satellite, versus the time that the satellite is available (in view). The aggregated tracking availability with all the Galileo satellites is also computed.
- **Satellite usage in PVT** – When a satellite is tracked it does not imply that it is used in the PVT solution. Several reasons can lead to its exclusion, such as signal strength, lack of ephemeris, constellation priorities, etc. This figure of merit gives the percentage of time that each satellite is used in PVT over the tracked time.
- **PVT Accuracy and Availability** – Increasing the number of constellations, the accuracy and availability improve in harsh environments where the portion of sky in view is reduced due to buildings and narrow streets.

The figure on the right shows the Galileo tracking availability (blue bars) for three different scenarios. The tracking reaches almost 50% in the Urban Mobile and Windowsill scenarios. The usage of those Galileo measurements in the PVT solution however (red bars) is reduced to 25%. It should be noted that both scenarios are quite challenging owing to the harsh environment conditions, i.e. featuring blocking elements such as buildings or bridges.



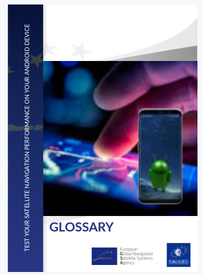


The benefits of multi-constellation PVT solutions are also evaluated. For instance using GNSS raw measurements, one can compute the GPS standalone PVT and the combined GPS + Galileo PVT. The figure on the right shows this comparison in a static scenario. The positioning accuracy using GPS is around 6.7 meters (50%). By adding Galileo, the accuracy improves up to 4.5 meters, highlighting the added value of Galileo in mass market devices.

Smartphone manufactures interested in GSA smartphone testing campaign can contact market@gsa.europa.eu

GPSTest & Glossary

To clarify and explain the parameters used in satellite navigation performance testing, the GSA has recently published a dedicated glossary for smartphone users. The glossary is based on the smartphone app GPSTest (by barbeauDev), which facilitates visualisation and understanding in real time signal reception and positioning performance parameters. Users will be able to assess the impact of external factors and to identify, for example, which satellites are being tracked, to which constellation they belong, the signal strengths, and the carrier frequencies (for dual-frequency devices).



GPSTest QR code

App available at: goo.gl/4dHZJu

Glossary available at: www.gsa.europa.eu

AUGMENTED REALITY BENEFITS FROM CENTIMETRE LEVEL PRECISION

Augmented reality can be defined as a real world view of the actual physical environment which is enhanced by overlaying computer generated information. The wide distribution of mass market mobile devices, such as smartphones, which are capable of handling graphical processing, new GNSS constellations, and more sensitive receivers, are enabling the use of augmented reality in a number of contexts. A common thread though is the need for high centimetre-level precision position and timing information, to ensure augmented reality applications function well.

Mass market AR is available today

© Gettyimages

Augmented reality applications need to overcome two key issues. First of all, the exact position and orientation of the device displaying the enhanced image must be known. Once this is ascertained, the environmental context has to be recognised correctly to ensure data is displayed in a realistic way.

Modern mass market devices can derive very accurate position information using multi constellation, dual-frequency GNSS receivers. This position can be further enhanced by fusing information from embedded MEMS devices such as solid-state compasses and magnetometers, which can provide information necessary for dead reckoning in case of issues with the signal.

MEMS devices also provide information on device orientation and position. Visual recognition of the environment based on previously stored information, and approaches such as SLAM are increasingly important thanks to decreasing memory costs and increasing computational power. Many of the smartphone AR technologies in use today can already perform basic image recognition to reliably identify flat surfaces such as floors and walls, resulting in applications such as Wallame or PokemonGo, and software platforms such as Google ARCore. Such functionality is also sufficient for applications bundled with the latest Samsung S9 and S9+, which can overlay basic information on outdoor locations, and stable views can be provided by combining dead reckoning with motion modelling and prediction. Manufacturers such as Apple are also working on displaying such information in a convenient way through devices such as iGlasses.

Enhanced AR requires sophisticated approaches

Although flat surfaces can currently be reliably identified, and the current precision of GNSS receivers is sufficient for basic AR applications, more sophisticated AR will require that real world objects are successfully identified, and that position is known with maximum accuracy. Given the variability and number of objects in the environment, image recognition techniques utilising neural network approaches will be required to ensure devices learn to recognise items appropriately.

For instance, in the indoor environment, building plans can provide information on the location of architectural or utility elements. Once these are recognised as such, combined with position information derived from sources such as Wi-Fi and Bluetooth, the exact position and view can be established. Only once such information is available can a virtual representation of real-life objects be created, to help ensure that augmented information is provided with the correct depth and in the correct position.

The increased precision of location could stimulate the appearance of new concepts built on augmented reality. For example it would be possible not only to access content in a specific location, but also to draw/create content in 3D space. The first basic 'drawing by location' apps are already available today, and the trend is expected to continue.

© Gettyimages

ROBOTICS REQUIRE TRACKING

Currently no single mass market device demonstrates all the features that one would typically expect of an advanced robot, however individual capabilities are featured in a number of consumer mass market devices. These specific functionalities are increasingly making their presence felt in the form of drones, boats, and cars, and have thus laid down the groundwork for the introduction of independent humanoid robots.

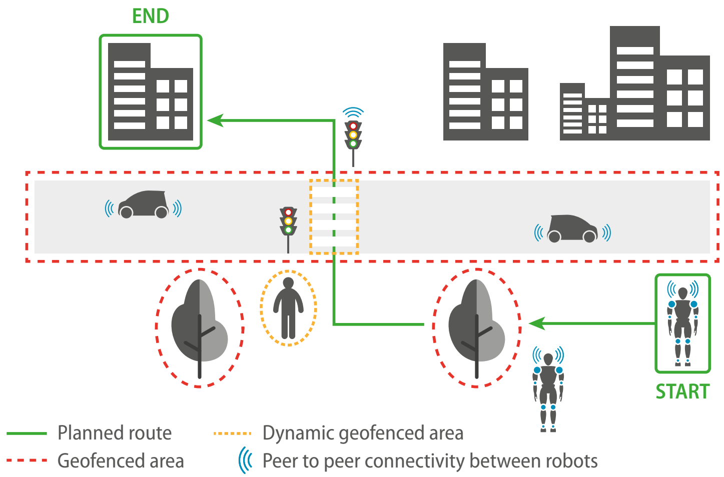
Augmented reality and autonomous navigation require similar levels of precision

Ensuring that robots can navigate the world autonomously and without causing accidents and disruption is a challenging task. The key is to automate image recognition and ensure that robots have accurate data on their position and orientation - a similar requirement to that facing augmented reality. In both cases, real world objects and their position in relation to the device/robot need to be understood with a high degree of precision. Localisation can be split into two categories; absolute and relative methods. In the relative case, position is determined in relation to surrounding objects (via odometry), and in the absolute case, a global reference and coordinate system is used (via GNSS). One approach to solve the autonomy problem of GNSS is to establish the position and orientation of the device/robot with accurate (and power efficient) GNSS receivers, combining GNSS derived information with data from sensors such as accelerometers.

Geofencing

In a future featuring humanoid robots that navigate external environments, there is a clear safety risk of a robot entering an area it should not (for example a highway). Solutions will undoubtedly utilise multiple sensors to ensure safety margins are delivered through independent, redundant solutions. Given the ever-increasing availability and accuracy of geospatial data, it is certain that geofencing, driven by GNSS, will provide one of these independent mitigations. Such solutions are already being used in consumer drones, preventing them from flying into restricted airspace, and in devices such as robot lawnmowers. Good connectivity will also be crucial as information on dynamic geofences, which vary depending on conditions and changes in the environment, have to be transmitted in a timely manner to robots and automated devices.

GEOFENCING AND DYNAMIC GEOFENCING SCHEME



Robotic exoskeletons are changing lives


© Suitx

Robotic exoskeletons aim to help people with injuries and movement problems to restore the motor functions of their bodies, and recover autonomy of movement.

Today this technology does not use GNSS.

In the future however it could enable an individual with limited mobility to walk through a street with minimal support. Theoretically, the exoskeleton could be programmed with a pre-set route with geofenced areas defined, and via dynamic positioning, a user could navigate through obstacles to reach a destination safely.

Aida

Aida is not a gadget or a simple "pizza robot".

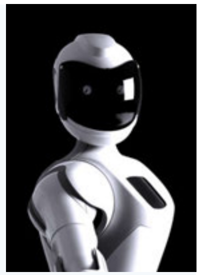
It integrates with delivery vehicles and automates the last 50 meters of the deliveries.

It can also avoid obstacles by stepping over them, unlike its less fortunate colleagues on wheels. But still, it is not capable of identifying unexpected potential dangers, and geofencing remains a must for Aida.

More at: unsupervisedai.blog/aida-3/


© unsupervisedai

Alice – a social robot!


© cybedroid

Alice's mission is to interact with people, particularly with disabled or elderly persons, to secure their environment and more generally to care about them.

Thanks to a Lidar and optical sensors, the robot can make a 3D map of its environment, and detect predefined objects and people.

Nevertheless, Alice could not fulfil its mission without geofencing.

More at: www.cybedroid.com/alice/

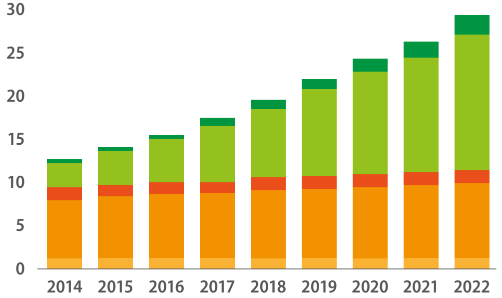
UBIQUITY OF PNT AND CONNECTIVITY ENABLE IOT

With predictions of 29 billion devices by 2022, IoT represents a huge market to address. Although the widespread use of GNSS in IoT has been traditionally hampered by its higher battery consumption and the widespread availability of low power networks, the development of innovative cloud-based GNSS receivers could reverse this trend. Moreover, the availability of PNT authentication service(s) may constitute an additional benefit for IoT applications.

GNSS and IoT

Of the estimated forecast of 29 billion connected devices by 2022, around 18 billion will be related to IoT. Already in 2018, mobile phones are expected to be surpassed in numbers by IoT devices, which include connected cars, machines, meters, wearables, and other consumer electronics. This growth will be driven by devices belonging to the short-range segment (e.g. connected by a radio signal within a range of up to around 100 meters such as Wi-Fi and/or Bluetooth), and by the wide-area category consisting of devices using cellular connections as well as low-power technologies, such as Sigfox, LoRaWan and NB-IoT.

INSTALLED BASE OF CONNECTED DEVICES



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	16	20%
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.3	8.6	3%
Fixed phones	1.4	1.3	0%
	16 billion	29 billion	10%

Source: Ericsson

The advent of these devices has already – and will in the future – considerably increased the number of services and applications that require positioning information. Although GNSS undoubtedly constitutes the most accurate and the only ubiquitous resource for locating IoT devices, it can occur that other, less accurate, positioning technologies are employed instead. This occurs in light of the stringent requirements of low-cost IoT sensors, in terms of low power consumption, in order to achieve larger battery lifetime that might not be fulfilled by current GNSS chipsets.

If on one hand the increasing widespread nature of low-power connectivity is already paving the way to the adoption of GNSS in IoT, with innovative modules entering the market integrating GNSS and LPWAN technologies, recent technological developments might further contribute to the usage of GNSS in IoT. A promising field of research is indeed focusing the attention towards the creation of a cloud-based GNSS receiver for IoT, in which the GNSS signal is processed in the cloud and role of the IoT sensor is purely to capture the GNSS signal and send it to the server. According to researchers of the Universitat Autònoma de Barcelona involved in the research, the use of the cloud GNSS receiver allows for savings in the energy consumed by the sensor, up to one order of magnitude compared with hot and assisted starts, and up to roughly 2.5 orders of magnitude in contrast with warm and cold starts.

IOT RELEVANT TECHNOLOGIES MAIN FEATURES

Technology	Device power consumption during use	Capability to provide location	Data transfer rate	Frequency	Estimated max useful range
GNSS	180 mW	Yes	-	1.0-1.5 GHz	Ubiquitous
Wi-Fi	300-1800 mW	Yes	54 - 1200 Mbit/s	2.4 - 5GHz	1.6 km
Bluetooth	100 mW	Yes	2.1 Mbit/s	2.4 GHz	100 m
4G	100-2000 mW	Yes	100 Mbit/s	2.0-8.0 GHz	<30 km
5G	100-2000 mW	Yes	1 Gbit/s	28GHz-300GHz	0.5-2km
LoRaWan	100 mW	Yes	27 kbit/s	0.4-0.9 GHz	<15 km
SigFox	10μW - 100 mW	Yes	300 bit/s	0.9 GHz	<50 km
NWave	25-100 mW	No	100 bit/s	0.9 GHz	16 km
Dash7	<100 mW	No	167 kbit/s	0.4-0.9 GHz	<5 km
NarrowBand IoT	100 mW	Yes	250 kbit/s	2.0-8.0 GHz	<35 km

Security, a growing concern

The rapid development of IoT with a growing number of connected devices provides solutions across a wide range of industries, offering new business opportunities for economic growth. This also however opens the door to a variety of new security threats. In fact, IoT devices may need to relay sensitive or regulated information, making them more vulnerable to spoofing attacks. This is the case for law enforcement applications such as monitoring of parolees, or commercial applications such as asset tracking. Within these applications the security of PNT information is important, as the overall system security is only as strong as its weakest link. In this regard, the authentication services offered by Galileo (OS-NMA and SAS) are likely to be valuable, as they will ensure the users that the PNT information is coming from the signal in space, and was not altered to gain an illegitimate advantage.

GALILEO SUPPORTS UBIQUITOUS POSITIONING IN CITIES AND CHALLENGING ENVIRONMENTS

Users of mass market devices such as smartphones, tablets or wearables require ubiquitous positioning. Urban areas however, represent challenging environments for the operation of GNSS receivers since high buildings reduce the portion of visible sky, thus limiting the number of satellites offering a direct line of sight with the device's antenna receiving the signal. This might lead to degraded performance, for instance when the geometry of visible satellites is not good, or even – if signals from a minimum number of four satellites is not received - to the impossibility of determining a position fix. Additionally, reflecting surfaces of buildings can cause an interference by multipath, resulting in the position fix computed by the GNSS literally 'jumping from one position to another' according to the set of measurements used to compute the position.

Galileo satellites boost ubiquitous positioning by not only providing additional satellites in view, adding to existing constellations, but their wide bandwidth signals are better able to cope with multipath interference. Thus modern multi-GNSS receivers can leverage better measurements from more satellites, with a higher probability of direct line of sight. This enhances basic GNSS performance factors such as availability, TTFF and accuracy, and finally supports the provision of a continuous and ubiquitous service to users.

Additionally, Galileo is the only GNSS offering navigation message authentication, a feature expected to be of high interest for application and service providers, since it could enable innovative commercially-sensitive applications and also enhance the quality of big data collection.

EGNOS is usually not integrated into mass market solutions, since SBAS requires continuous operation and may drain the battery, thus limiting the overall user experience. Nevertheless, some niche applications employ EGNOS in dedicated devices in order to take advantage of its enhanced accuracy and reliability.

E-GNSS CONTRIBUTION TO KEY PERFORMANCE PARAMETERS

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

* The Key Performance Parameters are defined in Annex III
** ••• = major contribution, capable of enabling new GNSS applications •• = medium contribution, enhancing the user´s experience so benefits (e.g. operational or at cost level) are achieved • = minor contribution, performances improved but no major difference at users´ level.

Enhanced GNSS user terminal

Fundamental Elements

The uptake of newly deployed GNSS is continuously improving the quality of service experienced by users, who expect this trend to continue in the years to come.

Galileo is continuously moving forward to offer innovative features by further enhancing positioning performance through tackling some important aspects. Two main enhancements are foreseen by the time Full Operational Capability will be declared:

- Open Service Navigation Message Authentication (OS-NMA), allowing users to verify that a navigation message is actually broadcast by a Galileo satellite and not by a potentially malicious source. This feature will increase the level of protection against GNSS spoofing, of which the likelihood of occurrence is increasing in many application domains.
- An enhanced, but fully backward compatible, Signal-in-Space (SIS) will include additional data transmitted in the I/NAV message, offering faster and more resilient Galileo PNT solutions in user devices.

By the time Galileo OS-NMA and I/NAV improvements are fully implemented, a new generation of enhanced receivers should be developed, tested and implemented to take advantage of these new features.

The objective of the grant is to design, develop and demonstrate in an operational environment a robust and close-to-market OS-NMA receiver, compliant with the upcoming SIS ICD and taking full benefit of these enhancements. In line with the overall mission of Fundamental Elements projects, the receiver shall target a specific application for which improved performance and trustworthiness are considered important.

FLAMINGO H2020

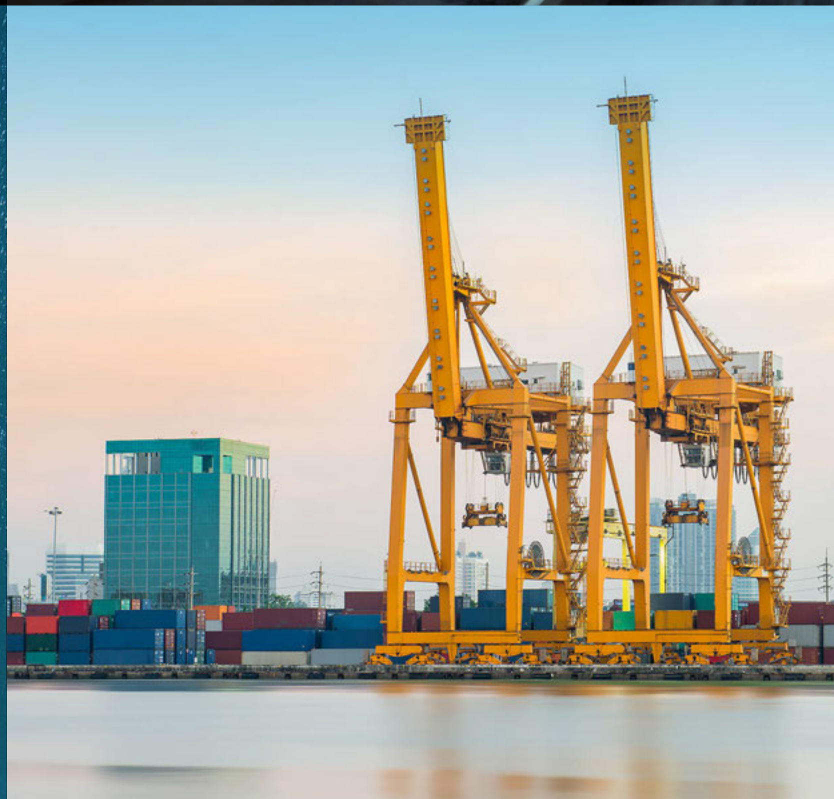
HORIZON 2020

The FLAMINGO H2020 project sets out to achieve enhanced location accuracy in the mass market based on initial Galileo services. The project aims to produce a service utilising multi-constellation, PPP and RTK mechanisms together with GNSS raw measurements which plan to provide accuracy of 50cm (95%).

FLAMINGO addresses mass-market devices such as smartphones and IoT devices, to facilitate and demonstrate reliable positioning and navigation in consumer applications.

FLAMINGO is cooperating with the European satellite navigation system (E-GNSS) to build the enabling infrastructure and services for high-accuracy positioning.


TRANSPORT SAFETY* - AND LIABILITY** - CRITICAL SOLUTIONS

* **Safety-critical applications** are defined as those that possess the potential to directly or indirectly cause harm to humans (death or injury), destruction of the carrier vehicle, damage to external properties or to the environment.

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

NAVIGATION PERFORMANCE MUST BE ASSURED FOR TRANSPORT SAFETY- AND LIABILITY-CRITICAL SOLUTIONS

Characterisation of the Transport safety- and liability-critical solutions segment

This macrosegment covers receiver technology for safety- and liability-critical applications in **aviation**, **maritime**, **rail** and **road** transportation. These sectors utilise mature safety- and liability-critical technology, which is built in accordance with rigorous standards and often subject to certification.

The development of **autonomous** capabilities across safety-critical transport applications is increasing the demand for **accuracy** and **integrity**, resulting in adoption of **high grade, robust GNSS** receiver technology as part of a tightly coupled suite of sensors, in order to provide the core positioning capability. This is prevalent in all sub-markets and in the professional drone sector.

PNDs* are part of the 'mass market' segment and excluded from this macrosegment. Timing and Synchronisation receivers are included in the 'high-precision and timing solutions' macrosegment**.

Key performance parameters***

Applications in this segment have always needed a high level of confidence in navigation performance (including integrity and robustness). Recently the term assured navigation performance has seen growing use. Although there is no formally agreed definition, it generally refers to the ability of the system to minimise integrity risk and continue to function in the presence of intentional or accidental interference.

* Personal Navigation Devices, such as GA moving maps, maritime chart plotters, and automotive portable units.
** Timing and synchronisation applications could be considered safety- and liability-critical, but the technology involved has more in common with high precision receivers.
*** The Key Performance Parameters are defined in Annex III
**** Power consumption could be critical for flying drones

The priority 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:** 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.
3. **Robustness:** jamming (particularly self-jamming in the case of liability-critical applications) can disable applications, whilst spoofing (including self-spoofing) could introduce serious safety or liability risks.
4. **Accuracy:** an increasing number of applications, particularly those with emerging autonomous capabilities, require high accuracy performance, and this parameter is becoming a higher priority for the macro-segment.
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 KEY PERFORMANCE PARAMETERS

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

● Low priority ● Medium priority ● High priority

THE ADVENT OF SELF-DRIVING CARS AND AUTOMATED DRONE TRAFFIC MANAGEMENT BRINGS DISRUPTIVE INFLUENCERS TO AN OTHERWISE MATURE MARKET

LEADING COMPONENTS MANUFACTURERS

BROADCOM	North America	www.broadcom.com
COBHAM	Europe	www.cobham.com
DJI	Asia	www.dji.com
ESTERLINE	North America	www.esterline.com
FURUNO	Asia-Pacific	www.furuno.com
GARMIN	North America	www.garmin.com
HEXAGON AB (LEICA, NOVATEL)	Europe	hexagon.com
HONEYWELL	North America	www.honeywell.com
JRC	Asia-Pacific	www.jrc.co.jp
MEDIATEK	Asia-Pacific	www.mediatek.com
OROLIA	Europe	www.orolia.com
QUALCOMM	North America	www.qualcomm.com
ROCKWELL COLLINS	North America	www.rockwellcollins.com
SEPTENTRIO	Europe	www.septentrio.com
STMICRO- ELECTRONICS	Europe	www.st.com
THALES AVIONICS	Europe	www.thalesgroup.com
TRIMBLE	North America	www.trimble.com
U-BLOX	Europe	www.u-blox.com

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

Receiver industry

Although the core GNSS technology can be common across the sectors, the other elements of a complete system are often tailored to the sector. For example, DME and VOR technology, unique to aviation, integrates alongside GNSS into flight management systems. In the rail sector, balise devices physically mounted on the sleepers of a track measure train locations. In maritime, strapdown INS is used, and the automotive industry uses radar and ultrasound sensors for functions such as adaptive cruise control and parking assistance.

The user requirements on underlying GNSS hardware technology is beginning to homogenise across sectors (which all increasingly demand higher accuracy, which effectively requires multi-frequency capabilities), there may yet be room for horizontal integration. For example, many chipsets under development for automotive applications may also be attractive for professional drone applications. Such consolidation may be necessary to address the inherently high development cost, long life cycles and corresponding technology obsolescence, as shorter lifecycles are adopted. Key to this will be how the safety-critical requirements across the different transport segments evolve.

For example, in the automotive sector it is likely that future vehicles will utilise GNSS chipsets certified to safety standards to support all on-board applications. These chipsets will need to deliver high accuracy and reliability to support automation. Once the cost has been absorbed, it would not be logical to include an additional chipset for other applications, such as integrated navigation displays, when there is already a high-performance sensor available.

Regulatory environment of the safety-critical value chains to be influenced by large innovators

The macrosegment is divided into domains that have 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.

The entry of influential, multi-national organisations at the top of the value chain (Amazon, Tesla, Google, DHL, Airbus, Uber and others) is changing user demand and applying 'upward' pressure to develop more rapidly than before.

These disruptive influencers are bringing not only significant funds and lobbying power, but also experience in developing and implementing at a faster pace of innovation.

At the same time, regulatory 'downward' pressures are reacting to constrain the developments within the existing regulatory frameworks, which are not equipped to deal with the innovation coming from the sector.

The opportunity now is for the innovators to help shape future regulations, to enable them to support the adoption of innovative technologies within the safety-critical environments. The focus is shifting from the detail of the technology itself, to the ways in which its performance can be measured so that safety is assured. Regulations can no longer be rule-based and instead need to be performance-based – supported by evidence provided by innovators to ensure confidence in the technology.

DUAL-FREQUENCY AND MULTI-CONSTELLATION SET TO BECOME COMMONPLACE

Multi-constellation adoption

Receivers for this macrosegment already largely have multi-constellation capabilities. The percentage of models supporting Galileo and BeiDou has risen since the previous issue of this report. The number of devices in the macrosegment that support all constellations is now approaching 30%, and it is foreseeable that it will be the most common configuration of receivers in future (as is already the case in other macrosegments).

Aviation however remains constrained to (SBAS supported) GPS-only solutions (outside of GA consumer devices) due to regulation, but future SBAS upgrades will incorporate multi-GNSS. This will take some time due to long product life-cycles and certification requirements. For example, EGNOS will augment both GPS and Galileo as part of V3, which is planned to enter service in 2025.

Automotive applications, such as eCall and advanced driver assistance systems are fostering rapid adoption of new constellations through regulation or the need to have sufficient signals available to deliver performance in constrained environments.

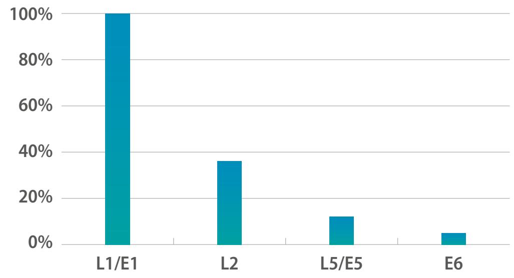
Multi-frequency adoption

In 2018 several new chipsets supporting multi-frequency were launched. The percentage of models which only support L1 has now fallen to under 65%.

The same SBAS upgrades which will push multi-constellation into the aviation market will also push the adoption of L5. In the meantime, the forerunners to ASIL/ISO26262 certified chipsets, for autonomous vehicles, already support multiple frequencies (L1 and a choice of L2 or L5 for the second frequency).

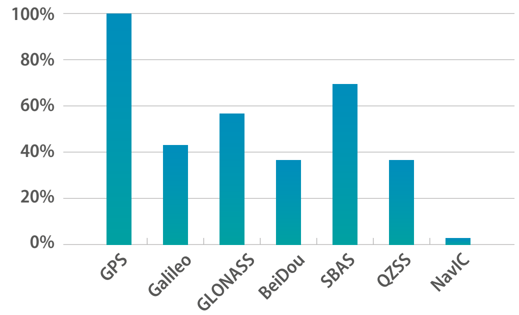
The segment as a whole is demanding high integrity, together with increased accuracy performance. Whilst sensor and data fusion will increasingly play a role, multi-frequency GNSS is the clear starting point to deliver such performance. For example, while merchant vessels typically use single frequency, multi-constellation receivers, Offshore Supply Vessels (OSV) are already using multi-constellation, multi-frequency receivers for dynamic positioning.

Frequency capability of GNSS receivers[1]



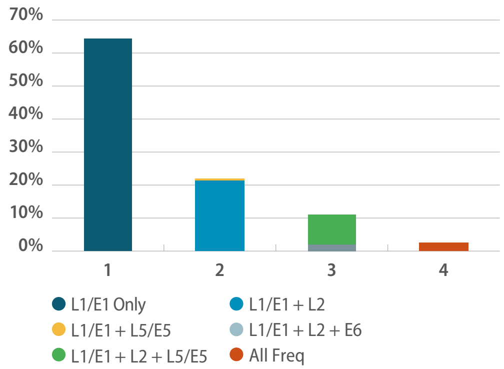
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



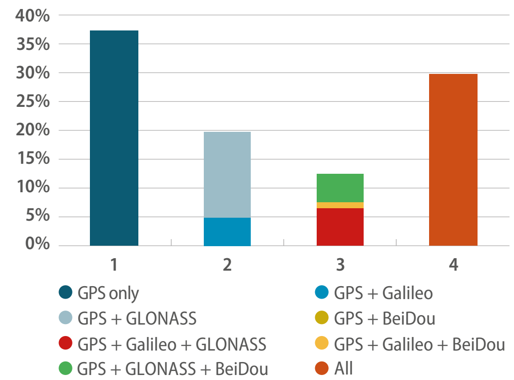
[2] shows the percentage of receivers capable of tracking each constellation

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 GNSS 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. In particular, models capable of supporting L1, L2 and L5 are captured as L1+L2+L5 in the database but are known to support either L1+L2 or L1+L5 in operation. In addition the data is likely to overestimate the applicability of some models, as it is based upon model availability and not sales volumes into the macro-segment.

REGULATION AND CERTIFICATION FOCUS RECEIVERS ON INTEGRITY

TYPICAL STATE-OF-THE-ART RECEIVER SPECIFICATIONS FOR THE TRANSPORT SAFETY- AND LIABILITY- CRITICAL SEGMENT

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	Not documented	Not documented
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 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.

The number of GNSS receiver suppliers for **aviation** is rather limited. Established manufacturers include Garmin, Thales, Rockwell Collins, CMC Electronics, Universal and Trimble/Ashtech, with more recent additions from Aspen/Accord and Avidyne. The latest certified airborne receivers are able to track 100+ GNSS satellite signals in addition to SBAS channels. These new receivers support RNP approach procedures, including those dependent on augmentation, and are able to support the performance needs of ADS-B surveillance applications.

GNSS receivers focused on **maritime** usually take the form of an integrated on-board rover receiver. Primary communication channels are radio beacons, satellite L band and VHF in AIS or VDES. Multi-constellation and multi-frequency devices improve navigation possibilities in obstructed environments. Nearly all marine receivers are SBAS enabled and SBAS usage is due to expand following the availability of ad hoc guidelines/regulations. Within RTCM, the GSA, EC, ESA and ESSP have drafted "Guidelines for the use of SBAS in maritime receivers" to foster this adoption.

A noteworthy innovation in **automotive** has been the market introduction by STMicroelectronics of the world's first multi-frequency GNSS receiver claiming autonomous-driving precision and automotive safety compliance (ISO26262), in February 2018. This allows for positioning up to decimetre level for Precise Point Positioning and Real Time Kinematic processing. This new receiver tracks satellites of all GNSS constellations at the same time on two frequencies. Usage of this GNSS receiver serves as a basis for automated systems such as adaptive cruise control, lane departure warning, auto-pilot and valet parking.

There is an ongoing trend of translating the well-consolidated integrity concept from aviation to other market domains, e.g. road with its peculiarities and challenges. This will require a tight integration of GNSS with all on-board sensors, as it is not only a function of absolute positioning but also of relative motion. It will also require deep environment awareness and ideally coordinated navigation..

Under development in EGNOS V3, new EGNOS capabilities will support the augmentation of both L1/E1 and L5/E5. This will allow future usage of multi-frequency receivers to achieve significant improvements in measurement and positioning accuracy in civil aviation, maritime and rail.

GNSS RECEIVERS ARE CORE TO THE DEVELOPMENT OF PREMIUM AUTOMOTIVE APPLICATIONS

Increased automation will require multi-frequency receivers

Ongoing development of multi-frequency GNSS receivers targeting premium automotive applications are behind the launch of the first multi-frequency chipsets for automotive applications in 2018. Although these chipsets might in a sense be considered consumer grade, they represent a link to the next generation that will be specifically designed to safety standards for autonomous driving.

MFMC receivers can improve positioning accuracy from a few metres toward decimetre level. Highly and fully-autonomous vehicles (Level 4 and Level 5 automation) will require chips designed to meet ASIL/ISO26262 standards. Today's chipsets provide a baseline for such future chipsets that will need to integrate key GNSS features, such as:

- Quality control of incoming satellite signal;
- Tracking all available GNSS signals in multiple frequency bands with carrier phase measurements;
- Raw GNSS data suitable to support precision positioning techniques such as PPP and RTK (supported by augmentation services targeting public and private applications);
- Tight and ultra-tight coupling with inertial and other on-board sensors.

InDrive and INLANE Projects

HORIZON 2020

The **InDrive** project (Automotive GNSS Receiver for High Integrity Applications on the Drive) developed an E-GNSS receiver, which uses data fusion (Bayesian engine for configurable E-GNSS software) and targets level 3 automation (conditional automation, such as advanced cruise control functions requiring a high level of accuracy, 50 centimetres or less).

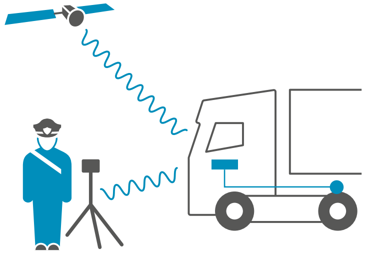
The InDrive receiver is responsible for processing the E-GNSS signal. It is used to estimate the level of confidence of the position in automated manoeuvres and to guarantee the false alarm rates and accuracy expected for the defined use cases.

inLane Lane Navigation Technology

The **InLane** (Low Cost GNSS and Computer Vision Fusion for Accurate Lane Level Navigation and Enhanced Automatic Map Generation) project proposes new generation, low-cost, lane-level, turn-by-turn navigation applications through the fusion of E-GNSS and Computer Vision technology. This will enable a new generation of enhanced mapping information based on crowdsourcing.

Delivering lane-level information to an in-vehicle navigation system and combining this with the opportunity for vehicles to exchange information, will give drivers the opportunity to select the optimal road lane, even in dense traffic in urban and extra-urban areas. Every driver will be able to choose the appropriate lane, thus reducing the risks associated with last-moment lane-change manoeuvres.

Smart tachograph



Within the EU, tachographs are fitted to around 6 million vehicles with a mass of more than 3.5 tonnes (in goods transport) or carrying more than 9 persons including the driver (in passenger transport). The new vehicles registered after June 2019 will need to be fitted with a smart tachograph, which aims to ease administration associated with tachograph and reduce tampering.

Smart tachographs incorporate GNSS and provide for automated recording of the vehicles' location at the start and end of the working day, together with one update after every three hours of accumulated driving time.

Security is critical for a tachograph, and so the device records a number of events, such as power supply interruption, security breach attempts and calibration data. Smart tachographs will also feed into intelligent transport systems, allowing easy integration with telematics systems.

Development, supply and testing of OS-NMA user terminal (PATROL)

Fundamental Elements

The initial OS-NMA Signal-in-Space transmission will enable a service experimentation phase in 2019, while reaching full service capability in 2020. Once fully operational, the free-of-charge navigation message authentication will be one of Galileo's key differentiators over other GNSS constellations. Before full service operation is achieved however, a new generation of OS-NMA-enabled user terminals must be developed, tested and implemented, which is where the **PATROL** project comes in.

The **PATROL** (Position Authenticated Tachograph foR OS-NMA Launch) consortium was awarded a contract by the GSA to develop, supply and test Galileo's Open Service Navigation Message Authentication (OS-NMA) in a user terminal suitable for smart tachographs.

The project will develop a user terminal capable of providing trusted position, velocity and precise time (PVT) data to smart tachographs and other positioning applications. OS-NMA is used in combination with other anti-spoofing techniques that are implemented at the receiver level and backed by standard IT security. The project is divided into two stages:

- Stage 1: aims to develop a first version of the User Terminal implementing OS-NMA to be tested against a full set of spoofing threats identified for the target application;
- Stage 2: will start once the SIS begins transmitting OS-NMA, and will have the objective to upgrade the OS-NMA User Terminal with additional anti-spoofing techniques in order to maximise the trustworthiness of the PVT solution.

EUROPE DEPLOYS ECALL AS INDUSTRY ANNOUNCES FIRST COMPATIBLE CAR MODELS

The GSA and the Joint Research Centre (JRC) have published Implementation Guidelines (in accordance with the EU Regulation 2017/79) to facilitate the implementation of eCall testing. They are also responsible for issuing the EC type-approval for eCall On-Board Units (OBU).

The GSA launched a test campaign where eCall device manufacturers had the opportunity to pre-test their devices, and ensure Galileo and EGNOS compatibility as a response to the European Commission publishing Delegated Regulation (EU) 2017/79. This Regulation stipulates that all new models of passenger cars (M1) and light duty vehicles (N1) must be equipped with eCall in-vehicle systems as of 31 March 2018. Industry players appreciated this opportunity and embraced the support to improve their products.

Similarly, the new UN Vehicle Regulation 144 on Accident Emergency Call Systems (AECS) entered into force in July 2018, and permits harmonisation of performance requirements and test procedures with other systems (e.g. ERA GLONASS).

The tests made it possible to thoroughly review the requirements and the test procedures, assessing a wide range of different testing implementation options. Among others, the tests assessed:

- Positioning accuracy under static and dynamic conditions;
- Cold start time-to-first-fix;
- Re-acquisition performance following signal outages;
- Receiver sensitivity.

Volvo is the first car maker to release European eCall

Swedish automobile manufacturer Volvo has taken the lead as the first car-maker to equip its vehicles with eCall. The new Volvo V60 was type approved at the beginning of 2018 and is already available on the market. It includes one eCall device, manufactured by ACTIA Nordic in Sweden and successfully tested by NavCert´s eCall Laboratory in Germany.

© Volvo

More models fitted with eCall are to be released shortly by Volvo during this year, and from 2019 on, all of the new portfolio of Volvo models will be eCall-enabled. Cars equipped with eCall use the same location source as for their in-vehicle navigation systems, and Volvo had incorporated Galileo compatibility in all models from the previous year. In fact, currently in Europe alone, around 50,000 cars with Galileo satellite navigation capability are on the road already, and more than 150,000 will be enabled at the end of 2018.

Summary of eCall GNSS compatibility tests results

GSA/JRC guidelines were published to illustrate how the requirements stated in the eCall Regulation might be translated in practice into a suite of test scenarios, acknowledging that several alternative testing configurations and implementations can be compliant with the EU Regulation. The full list of recommendations is available in the Implementation Guidelines at: www.gsa.europa.eu

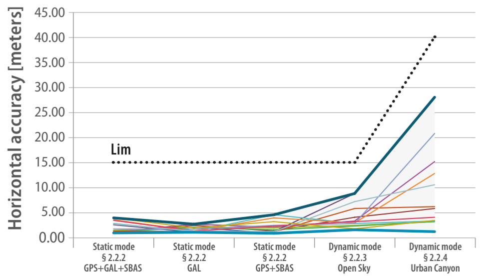
The testing campaign involved 13 eCall models from key automotive suppliers. Most of the units demonstrated their readiness to undergo formal type approval. In some cases, recommendations were provided to support further improvements of the actual compatibility with the positioning services provided by Galileo and EGNOS.

In terms of positioning accuracy in static conditions, some eCall units demonstrated that a Galileo-only solution outperformed GPS+SBAS.

In dynamic scenarios, the observed overall horizontal position errors were in all cases below the specified limit, despite an important dispersion of the results.

All the units demonstrated full compliance with the cold start TTFF targets, both when simulating a signal power of -130 dBm (60 seconds) and -140 dBm (300 seconds).

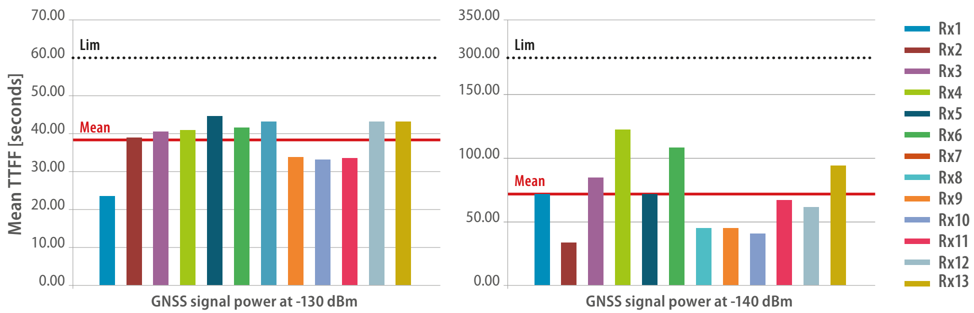
eCall Horizontal Positioning Accuracy



In the complete suite of test scenarios, the sensitivity test was certainly one of the most demanding for the eCall units. The majority of them successfully passed this sensitivity test, and some of them demonstrated an optimal use of Galileo signals in the positioning solution.

Note: All plots refer to the test procedures defined in Annex VI of the EU Regulation 2017/79.

eCall cold start TTFF



GNSS UPTAKE IN RAIL AND LOGISTICS IMPROVES OPERATIONAL SAFETY AND EFFICIENCY

Rail networks set to benefit from GNSS

The European rail sector is continuing its efforts to establish an architecture that would allow the introduction of a GNSS-based train-positioning concept in the European Rail Traffic Management System (ERTMS). Satellite-based positioning has been prioritised by the railway community as one of the five key game changers for ERTMS evolution, in the frame of the latest ERTMS Memorandum of Understanding. In 2017, preparatory work for the first commercially operated line intending to use GNSS was launched in Italy on the Pinerolo-Sangone line, which is further fostering the innovation focus within the European space and rail industry by enhancing technical developments. Key target performances and safety requirements were derived from the functional hazard analysis performed on a selected ERTMS reference architecture as part of the GSA H2020 STARS project. Together with the GNSS performance measurement campaign, the results from STARS form a basis to finalise the train positioning system architecture by major rail stakeholders within the Shift2Rail X2Rail2 project, which will also influence the future developments of GNSS receivers with specific requirements (multi-frequency, multi-constellation and SBAS features). Furthermore, in the case of non-safety relevant applications, operators continue to equip their fleets (in specific cases including the freight wagons) with GNSS receivers to provide improved supply chain visibility for the logistic service providers and their customers, used to similar performance levels in other land transportation modes. In this case, the user requirements on GNSS are comparable with road track & trace solutions, with a potential to exploit also Galileo OS-NMA to add further confidence in the position of the railway assets.

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Managing the transportation of dangerous goods with authenticated GNSS

Dangerous goods for transport include substances and articles that have explosive, flammable, toxic, infectious or corrosive properties. Having fully reliable knowledge of the position and the status of the vehicle can be an essential element in effectively preventing or resolving a crisis of this kind. In addition to the basic tracking capability, GNSS can offer enhanced security through Galileo's authentication features, which can help detect spoofing attacks. CEN Workshop Agreement (CWA) 16390 is the technical specification for the development of products and applications based on the services provided by chipsets with EGNOS/EDAS/multi-GNSS and Galileo OS-NMA support. The United Nations Economic Commission for Europe (UNECE) agreed to introduce the use of telematics, taking into account CWA 16390:2018 for the international transport of dangerous goods.

Consistently Optimised Resilient Secure Global Supply-Chains (CORE)

The CORE project covers the development of applications and products based on services provided by EGNOS. This project is funded under the Seventh Framework Programme of the European Commission (FP7) and aims to increase the reliability, speed and efficiency of trade and coordination, while enhancing the effectiveness of global trade oversight. Project CORE's intent is to demonstrate how a cost effective, fast and robust solution can be obtained by integrating interoperability, security, real-time optimisation and resilience.

Satellite Technology for Advanced Railway Signalling (STARS)

STARS HORIZON 2020

Predicting achievable GNSS performance in a railway environment and creating a universal approach to this issue, especially for safety-critical applications within ERTMS, is the key role of the STARS project, continuing its development efforts with the involvement of UNISIG companies and the coordination of UNIFE.

Within the project activities, the necessary field measurement procedures were delivered and approved. According to these procedures more than 150 days of measurement data for rail environment characterisation were collected from over 3,000 km of representative railway lines in different environments, including challenging terrain such as mountains, those under heavy tree canopies, or with many multipath generating elements. This data is currently undergoing detailed analysis to determine the implication on the train positioning subsystem architecture, which must be able to mitigate risks associated with potentially wrong pseudo-range measurements resulting from variations in the local environment.

RHINOS

RHINOS HORIZON 2020

The Railway High Integrity Navigation Overlay System (RHINOS) project sought to tackle the challenging environment (in terms of GNSS reception) typical to rail networks.

RHINOS bridged the existing gap between the aviation SBAS and railway ETCS standards by international standardisation of the SBAS-R interface. The new standard will support interoperability in railway signalling based on the Virtual Balise concept.

Moreover the project developed a new concept for the rail community using GNSS infrastructure realised for aviation applications, with additional layers to meet the rail requirements. Furthermore, it defined an architecture of a train Location Determination System (LDS) and the supporting infrastructure needed for its performance assessment. Finally the project also defined a strategic roadmap for the adoption of an international standard.

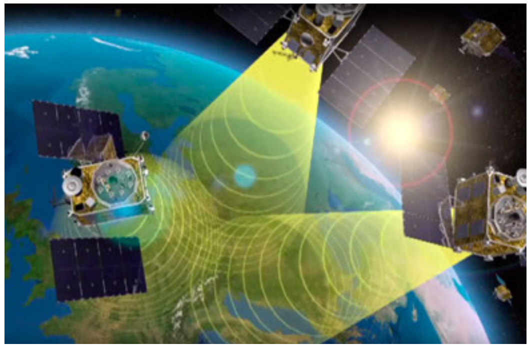
AVIATION LOOKS BEYOND GPS L1

GNSS is a key technology of the communications, navigation and surveillance infrastructure in aviation. It can support not only navigation applications in all phases of flight, for example LPV approaches and Required Navigation Performance, but also surveillance applications such as ADS-B. Long product life cycles and the safety-driven need for standards and certification has meant that aviation use of GNSS is almost entirely restricted to one constellation and frequency. The adoption of multi-constellation and multi-frequency however is just around the corner.

EUROCAE Working Group 62 (WG62) was created in 2002 in the context of Galileo satellite deployment and GPS modernisation. In mid-2013, the SBAS interoperability Working Group decided to adopt incorporation of a second GNSS frequency using the L5/E5a signal. The EC subsequently published the interim antenna Minimum Operational Performance Standard (MOPS) for GPS and Galileo L1/E1, L5/E5a in 2014. Since then, WG62 has focused its work on standardisation of Galileo as well as dual-frequency and multi-constellation receivers capable of processing signals from Galileo, GPS and SBAS.

The GSA has commissioned a Fundamental Elements project to specifically support the development of SBAS Dual-Frequency Multi-Constellation (DFMC) receivers aimed at the level of maturity required for flight tests (i.e. TRL 7). The project will develop the minimum operation standards, test and validate the DFMC SBAS receiver, by following the standardisation processes from EUROCAE and RTCA.

With the expectation of developed standards and proven technical and operational adoption, EGNOS V3 will enter service in 2025 combining the use of GPS and Galileo. Use of L5 will improve service robustness against errors and propagation delays caused by ionosphere. It will be the first such regional satellite augmentation system to employ dual frequency.

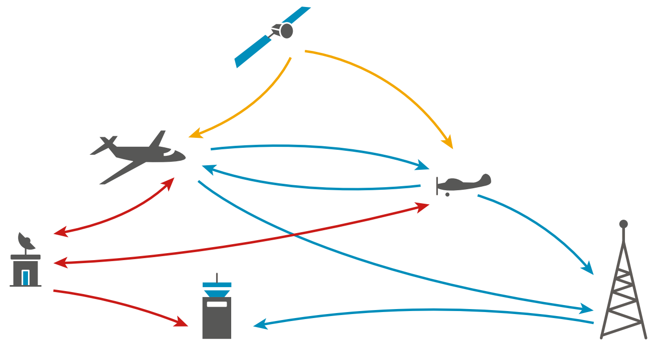


Role of GNSS in surveillance

Whilst the most obvious use of GNSS in aviation is for navigation, it can also be used for surveillance.

ADS-B

Automatic Dependent Surveillance – Broadcast (ADS-B) is a technology where an aircraft determines its position, typically via GNSS, and broadcasts it periodically to allow tracking by air traffic controllers and other aircraft. In some locations ADS-B is the primary means of surveillance, as ground radar infrastructure may not be fully developed or is not economically feasible, but GNSS ubiquity offers a solution.



In Europe, the Surveillance Performance and Interoperability Implementing Regulation No127/2011 (SPI IR) mandates aircraft (>5700kg or 250kts) to be compliant with Mode S and ADS-B Out requirements by 2015. Due to delays in certification and availability of required equipment, as well as industrial capacity constraints for equipping aircraft, the date by which operators are to comply with the SPI IR requirements has been amended and delayed to 2020.

Although ADS-B is a current technology, recent developments of **space-based** ADS-B receivers mean it is likely to see increased adoption. Two flight tests of the satellite-based ADS-B system were recently completed by the FAA, Nav Canada and Aireon, using ADS-B transponders that operate at 125 watts. One third of the 66 space-based ADS-B receivers, which are free of the line-of-sight limitations experienced by the terrestrial-based ADS-B and radar technology, have successfully received data during the tests. The introduction of MCMF in the near future is expected to have a positive impact on robustness and integrity.

ASAS

Airborne Separation Assistance System (ASAS) is a collection of applications that utilise ADS-B to transmit information from an aircraft to the ground and other aircraft. They enable the crew to keep aircraft separate from each other, and provide flight information concerning the surrounding traffic. Expectations from ASAS are to enhance safety in the cockpit regarding situational awareness, autonomous modes of operation, and guidance presented directly to the flight crew. These have a positive effect on capacity, flight efficiency as well as costs and the environment.

Raw Data in ADS-B

Raw GNSS measurement is envisaged to be the future of surveillance. Broadcasting raw data (including pseudo-range and carrier phase data) within ADS-B messages in place of the derived position coordinates enables aircraft to estimate the flight paths of other aircraft more accurately, allowing safer operations even under impaired conditions. Raw measurement is also a way to achieve true integration with systems like DME, eLoran, Iridium as well as with cooperating UAVs and signals-of-opportunity. These improvements only require a software update of the ADS-B message content, and SAE international has already begun developing standards to bring this approach into the mainstream.

AUGMENTED GNSS DRIVES THE EVOLUTION OF AVIATION NAVIGATION

Hybrid sensor solutions for positioning and navigation

© GSA

Aviation has long used a combination of GNSS and inertial technology in its navigation systems. Research into computer vision-based navigation systems has been underway for some time, but recent developments in Enhanced and Synthetic Vision Systems (EVS and SVS) may provide new possibilities in IFR or marginal conditions.

EVS is a system which provides the pilot with an image which is better than unaided human vision, by relying on imaging sensors and a head-up display (HUD) for descent below Decision Altitude, whereas SVS combines 3D data into intuitive displays to provide improved situational awareness to flight crews. Both systems facilitate a reduced pilot workload by presenting information that is easy to digest during the demanding phase of flight. Combining both solutions would mean superimposing database-driven synthetic vision and real-time sensor images on the same display, realising the benefits of both systems to enable aircraft access to more runways. The Augmented Approaches to Land (AAL)* project carried over ten trial flights and about 70 full flight simulation sessions to validate the "Enhanced Flight Vision System to Land" concept of operation. Data collected during these trials assessed the Key Performance Areas of Safety, Environment, Human Performance and Airport Capacity, demonstrating that they met requirements.

ARAIM developments

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With the availability of new GNSS constellations and new signals, there is a strong potential to expand the role of Receiver Autonomous Integrity Monitoring (RAIM) for aircraft navigation, and develop a new GNSS integrity method capable to support aircraft operations for all phases of flight, including worldwide coverage for LPV-200.

Advanced Receiver Autonomous Integrity Monitoring (ARAIM) is an integrity concept that relies on multiple GNSS constellations and dual frequency to provide global coverage for horizontal and vertical guidance for aircraft, similar to the service that SBAS already provides regionally. The ARAIM concept was initially envisioned by the GNSS Evolutionary Architecture Study Panel, followed by a working group, WG-C, established under the EU and US agreement that defines the principles for cooperation activities in the field of satellite navigation. The WG-C aims to promote cooperation on the design and development of the next generation of civil satellite-based navigation and timing systems. To respond to the ARAIM roadmap, the GSA aims to fund two projects on the development of the ARAIM prototype receivers. These projects will develop, test and assess the performance of ARAIM receiver prototype(s), characterise and validate the local effects on the threat model and contribute to the standardisation activities. The development of ARAIM enabled by Galileo will enhance autonomous on-board integrity monitoring, which will allow the use of the ARAIM functionality for all phases of flight up to CAT I approach for several decades.

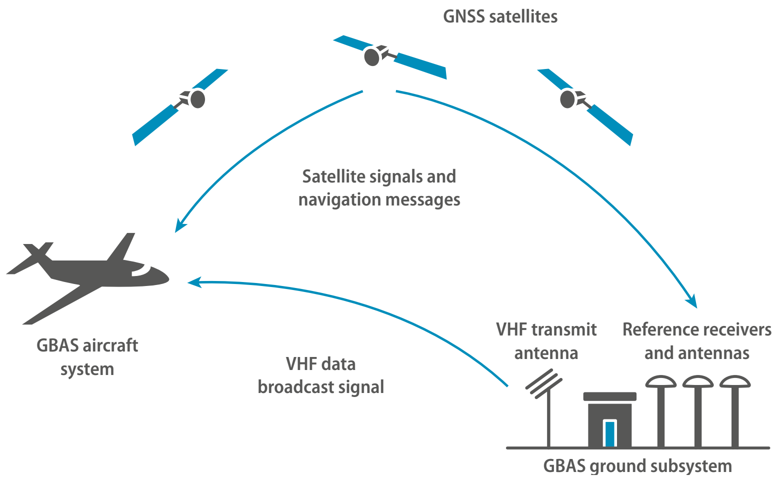
* Evaluation of GPS L5 and Galileo E1 and E5a Performance for Future Multi-frequency and Multi-constellation GBAS, DLR, August 2016.

GBAS with Galileo

Ground Based Augmentation Systems providing augmentation to Galileo and GLONASS signals could enable multi-constellation and multi-frequency precision approaches, and have the potential to overcome ILS limitations and enable CAT III landings regardless of visibility.

Approaches with GBAS are more flexible than ILS and can enable more efficient use of infrastructure. One GBAS station can serve multiple runways for approach as well as departure. Currently, GBAS is only available to CAT I minima. The development roadmap envisages regulatory approval in the coming years for GBAS evolutions under GAST-E (Dual Frequency) and GAST-F (MCMF), delivering CAT II and CAT III minima respectively.

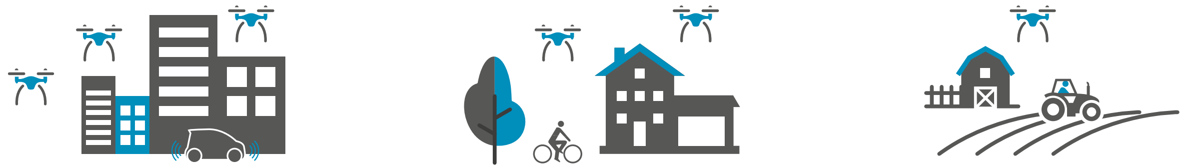
MCMF GBAS will have different potential error sources and failure modes than GPS L1 C/A code measurements only, which needs to be assessed in order to assure integrity. Dual frequency carrier phase measurements would allow mitigation of ionospheric delay and multipath, as well as smoothing noisy measurements. Experiments conducted by DLR (2016) have shown that "the raw noise and multipath level of Galileo signals" "are smaller than that of GPS L1", on which GBAS is currently based. In particular, Galileo E5a is significantly less affected by multipath than E1/L1 signals. Ultimately, MCMF GBAS is expected to have improved performance in terms of noise and multipath, which could deliver better robustness, and thus higher availability than existing GBAS.



PROFESSIONAL DRONE APPLICATIONS DRIVE TECHNOLOGICAL PROGRESSION

Precise and reliable tracking information, connectivity, hybridisation of various data sources, and harmonised regulation will be critical in allowing the drone market to develop to its full potential.

The high volume of drone traffic expected in the near-term future will require automated drone/UAS traffic management systems (UTM), which will maintain contact with each drone and dynamically change its flight route in response to the changing airspace environment and any detected traffic hazards. A high proportion of drone traffic is expected to consist of short-range flights primarily travelling at low level (< 500 ft.), where multiple obstacles are present. Airspace access limitations (geofences) will further compound the situation. Geofences are expected to change dynamically due to factors such as weather, events or emergencies. Therefore, reliable connectivity solutions will be critical for enabling drone traffic. The technologies used might change depending on the environment, for instance in a complex urban setting precision and high connectivity will be crucial, while in a rural setting more emphasis might be placed on ensuring that connectivity is maintained over long distances. New aviation certified GNSS receivers might have to be developed for drone applications in complicated low-level environments, as the accuracy of receivers used in manned aviation today will not be sufficient, and miniaturised survey receivers (with Multi-Constellation Multi-frequency, Real-Time Kinematic and Precise Point Positioning) will have to be developed. In such settings, autonomous operations will greatly benefit from hybridisation of data from other sensors such as cameras. Technologies such as neural processing will use information derived from visual sources to verify the position of a drone and identify objects of interest.



	Urban environment	Suburban environment	Rural environment
	GNSS: Centimetre level accuracy, high update rate **Connectivity:** High bandwidth important, range might be compromised		**GNSS:** Metre level accuracy, update rate can be compromised **Connectivity:** Long range connectivity, bandwidth might be compromised
Example technology requirements:	Dual-frequency GNSS, differencial GNSS, 5G	Dual-frequency GNSS, 5G, Satcom	Low cost GNSS, Satcom, ADS-B

MapKITE

mapKITE HORIZON 2020

The MapKITE consortium developed a novel, low-cost, terrain mapping solution which is heavily reliant on GNSS positioning, navigation and timing (PNT) technology via a combination of terrestrial and aerial surveys. A mobile ground control station – a vehicle – provides real-time navigation information to a drone, which maps terrain whilst tracking the vehicle. This 'Kinematic Ground Control Point' (GCP) practically eliminates the need for traditional GCPs and can achieve a check point accuracy with a mean error of 3.4 cm for easting/northing and 8.6 cm for height. The Galileo E5 AltBOC signal helps to address multipath issues, which mitigates error in the ground vehicle navigation solution. This in turn enables the combined system to achieve its high performance level.

Drone regulation updates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EASA is nearing the publication of the final version of joint European Regulation for drones outlined in NPA 2017-05 and Opinion 01/2018. The regulation proposes to place different requirements on drones using a risk-based approach. The increased resilience provided through Galileo will be pivotal for ensuring adequate safety can be maintained. Separately, the European Commission and SESAR Joint Undertaking are pursuing the development of services which will enable European U-space. The intention is to introduce U-space in several steps (U1 to U4) progressively enabling autonomous Beyond Visual Line of Sight (BVLOS) operations in increasingly complex environments. To ensure safety, certain minimum requirements will be placed on the integrity and security of drones depending on the environment they will function in. Owing to their inherent security, Galileo and EGNOS are well situated to be used in challenging environments. Initially operations will be introduced as IFR traffic into controlled airspace. Once sufficient detect and avoid technology is developed, BVLOS drones are expected to also seamlessly integrate with VFR traffic. To date several calls for proposals have been announced to develop the U-Space concept.

SkyOpener

HORIZON 2020

The SkyOpener project aims to integrate drones into the civilian airspace. This solution will combine tracking using the Galileo and GPS satellite constellations and SATCOM communication services, combining track and detect and avoid functionalities. SkyOpener's technology will allow drone integration with manned traffic, eventually easing the transition to the U-Space U4 step. GNSS (including Galileo and EGNOS) will provide guidance, geofencing, tracking information for drone traffic management and georeferencing data for survey data collected by the drones. Initial project results will be available at the end of 2018, but the project has already showed that it is feasible to use drones for long-range survey missions, and is expected to provide a number of benefits. For example, SkyOpener is expected to increase the availability of radio communication from 80-90% to 99.9%.

IMPROVEMENTS ARE UNDER DEVELOPMENT FOR MARITIME SURVEILLANCE, TRACKING AND MONITORING

SBAS for maritime users

GNSS is the primary means of PNT at sea, but integrity and accuracy requirements mean that standalone GNSS is not sufficient for coastal or port operations. The International Association of Lighthouse Authorities (IALA) Differential-GNSS (DGNSS) system has been the solution for many years, but today the maritime community is also considering using SBAS, which has complementary merits to the marine radio beacon DGNSS.

In the short term, IALA is considering SBAS as an alternative/supplementary source of corrections for the current DGNSS system, and published guidelines for the retransmission of SBAS corrections using MF radio beacons and AIS stations (G-1129) in RTCM format in January 2018. The proposed system is fully compatible with existing (non-SBAS) shipborne DGNSS receivers.

In the longer term, SBAS could provide a maritime safety-of-life service as it currently does for aviation, and be used to its full potential (almost all marine receivers are SBAS-compatible and could benefit from such service). Maritime users would enjoy a much larger service area than with DGNSS. Such a service can only be realised when the SBAS provider commits to doing so, however, (and this is the case for EGNOS V3), but also when receivers are available that implement SBAS processing in an adequate manner. This is why the GSA is currently supporting the testing and development of such receiver guidelines drafted within RTCM, through the MAREC project.

AIS improvements

AIS is a coastal tracking system, which automatically broadcasts information about the ship to other ships and coastal authorities. AIS communication takes place using a VHF transponder (with two frequencies 161.975 MHz and 162.025 MHz), using a bandwidth of 25 kHz. This application supports safe navigation and collision avoidance. The fact that AIS receivers have also been hosted on Low Earth Orbit (LEO) satellites increases the coverage. Vessels can now detect signals operating beyond 40 nm range from land-based AIS receivers, thus contributing to the utility of AIS as a fisheries' monitoring tool. Concerns over maritime security and illegal fishing drove the introduction of mandatory AIS in fishing vessels (mandatory in EU for vessels longer than 15m).

Galileo's OS-NMA could provide an added benefit in AIS applications through increased resilience. The OS-NMA is capable of protecting users from spoofing attacks by digitally signing the Open Service navigation message in the E1 band.

In addition, AIS is used in EPIRBs as a homing signal and by search and rescue helicopters to find vessels in distress.

spyGLASS Project

HORIZON 2020

The Galileo-based Passive Radar for Maritime Surveillance project brings Passive Bistatic Radar (PBR) based on Galileo coverage (that ensures any point on Earth is permanently illuminated by several satellites) to marine surveillance. The problem addressed by the project is that using AIS transponders does not guarantee the identification of non-cooperative vessels potentially involved in various illegal actions.

The project is developing an industrial design and prototype for a global maritime traffic surveillance system made up of PBR, composed of a transmitter (Galileo satellite), a reflector or target (vessel), and a ground-based receiver installed in a control centre. The control centre can also be mobile (i.e. vehicle based), in order to allow monitoring near a specific area of interest.

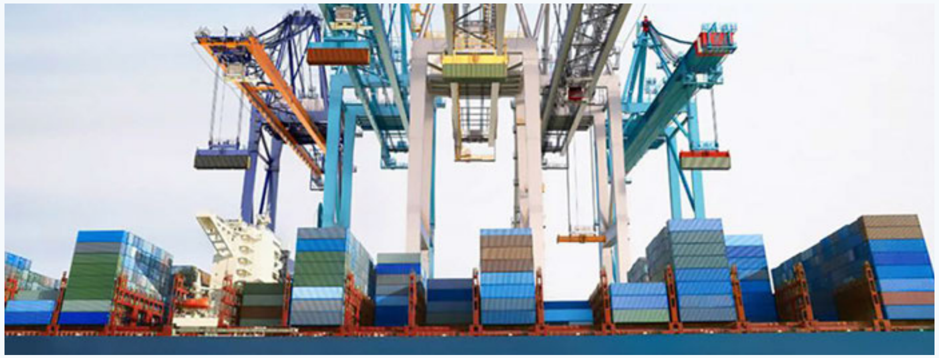
Automation in ports

LOGIMATIC HORIZON 2020

The LOGIMATIC project, focusing on Smart Port Vehicle Management, proposes a solution to enable the automation of existing port vehicles in terms of location and navigation via tight integration of E-GNSS and on-board sensors.

The focus of the project is on straddle carriers in container terminals. LOGIMATIC relies on a combination of a multi-constellation GNSS receiver augmented by EGNOS and on-board sensors to provide a continuous, reliable and accurate estimation of the position and velocity of the platforms. The solution is integrated on the Straddle Carrier as part of an On-board Navigation Unit (ONU) connected to the centralised system for monitoring purposes, and to exchange action plans and progress reports on their daily tasks.

LOGIMATIC is exploring tight integration of sensors, novel cyber security approaches to GNSS spoofing detection and integration of GIS-based data.

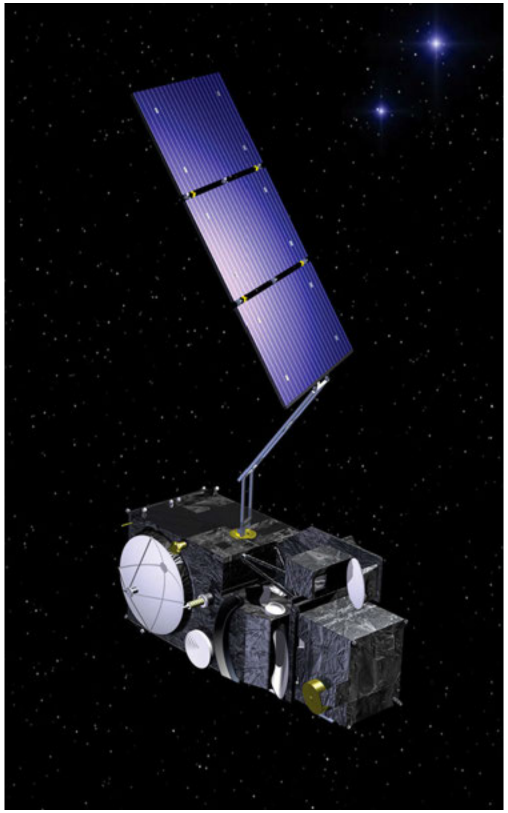


GNSS IS SEEN AS A KEY TO PROVIDING RELIABLE PNT IN SPACE

Space-borne GNSS receivers offer missions a suite of capabilities: navigation (particularly precise orbit determination), attitude determination, precise timing, Earth science applications (as a remote sensing tool) and navigation for launchers. Compared to terrestrial receivers, whilst space-borne receivers need to cope with extreme dynamic forces, environmental radiation, and the mechanical stresses of launch, overall they provide the same PVT services as their terrestrial cousins.

The use of GNSS is space has a long history; the first space-borne GNSS receiver was utilised in Landsat 4 on 16th July 1982, and have been commonplace since the start of the 1990's. NASA has been working on specifying the performance of GPS within its Space Service Volume (SSV) since 2004.

For some Low Earth Orbit (LEO) missions, such as CubeSats, COTS FPGA hardware programmed with specialised VHDL descriptions adapted for high dynamics (including widening Doppler windows) are common practice. This is only feasible if missions have short lifetimes and do not cross Van Allen belts whose high radiation levels require radiation-hardened devices.

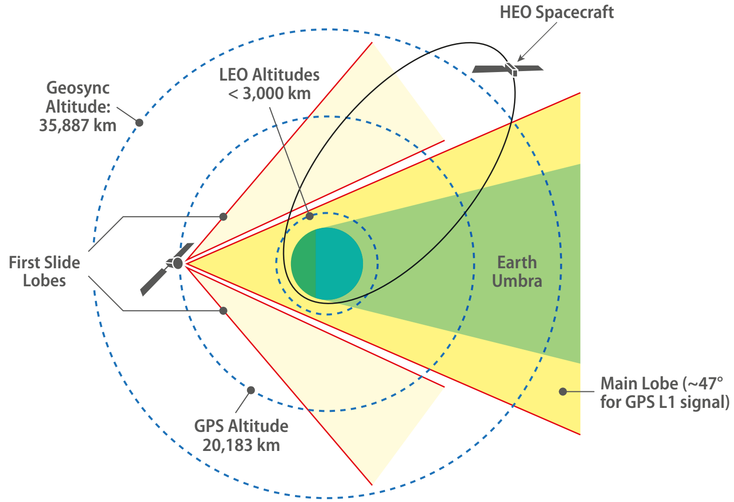


Galileo in spacecraft

2017 saw the first GPS/Galileo combined receiver flown in space as an experiment on the ISS. The GAlileo Receiver for the ISS (GARISS) mission will demonstrate and analyse combined GPS/Galileo L5/E5a performance in orbit. Utilising existing PNT code for a Software Defined Radio (SDR) Galileo receiver, the mission also demonstrates the flexibility of SDR, and allows development to continue based on operating data. The mission operates by transferring the waveform from ground support equipment to the on-board test bed, collecting GNSS raw measurements, and computing PVT on board of the ISS.

A key European development is the AGGA (Advanced GPS Galileo ASIC) space-grade component developed by the European Space Agency (ESA). Now upgraded to version 4, AGGA-4 includes 36 GNSS channels in combination with an on-chip powerful LEON-2FT microprocessor for software processing tasks. The AGGA-2 predecessor flew in practically all ESA Earth Observation LEO satellites since 2006. AGGA-4 is being commercialised as a radiation hardened ASIC component and also as part of an advanced Evaluation Kit. It is also available pre-integrated into state-of-the-art GNSS space receivers, providing capabilities for processing multi-frequency and multi-GNSS – including Galileo signals. AGGA-4 now has a first flight heritage mission in GEO as of November 2017, and has also been selected for a large number of LEO and GEO missions.

RECEPTION GEOMETRY FOR GPS SIGNALS IN SPACE



© Adapted from NASA (www.gps.gov/governance/advisory/meetings/2016-12/parker.pdf)

Beyond Low Earth Orbit GNSS is in use, and multi-constellation provides improved availability

Above 3,000 km and up to 36,000 km (GEO), the use of single constellation GNSS is challenging due to shadowing of GNSS signals by the Earth's Umbra (illustrated above). Working with 'aggregate signal' (including side lobes) radically increases the number of satellites in view. NASA's Magnetospheric Multiscale (MMS) mission set records in 2016, for the 'highest' ever GPS fix at over 70,000 km, and also the fastest operational GPS receiver, at 35,000 km/h at perigee. At the time of publication, the UN's International Committee for GNSS is preparing to issue a document on Space Service Volume. This aims to describe GNSS use between LEO and near GEO. Interoperability between GNSS is seen as key to providing reliable PNT in space, especially in GEO, and this is likely to be most easily implemented via use of a common intermediary reference clock or timescale.

Multi-constellation provides further benefits, as reported e.g. by NASA researchers: "A preliminary geometric analysis using only main beam 'spill-over' Earth coverage signals from each constellation shows that combining GPS and Galileo would enable an average of three satellites in view at GEO, with four satellites in view 30 percent of the time. By comparison, using all constellations (GPS, Galileo, GLONASS, BeiDou, QZSS, and NavIC) would enable four satellites visible at GEO approximately 95 percent of the time using the signals in the L1 frequency band[1]."

1 Navigating in Space Taking GNSS to New Heights, Inside GNSS November December 2016.

SEARCH AND RESCUE BEACONS WILL SOON BENEFIT FROM GALILEO RETURN LINK SERVICE

Galileo is providing a Search and Rescue (SAR) Initial Service that contributes to saving five lives per day, with greater anticipated benefits when the Return Link Service (RLS) becomes operational in 2019.

Cospas-Sarsat is an international satellite communication system that detects and locates activated emergency beacons and transmits distress alerts to SAR authorities. The role of GNSS in providing precise positioning information will become increasingly central, with continuous technological improvement and increasing penetration of multi-constellation capabilities in beacons. In particular, the GSA is committed to supporting the introduction of Galileo's added value service, RLS, which will enable enhanced capabilities such as acknowledgement of receipt message to the distress beacon within 15 minutes, and remote activation of beacons, as well as the possibility of detecting false alarms.

With the production of SAR beacons increasing at an annual growth rate of 5% (estimated based on 2017 data) and considering that 70% of the surveyed SAR manufacturers declare the inclusion of Galileo positioning in their product roadmaps, the Galileo RLS service is perceived to bring added benefits to the current SAR operations.

SAR Beacons

© ECA Group

An essential component of the Cospas-Sarsat system is the distress radio beacons. There are three types of 406MHz beacons – Emergency Locator Transmitter (ELT) for aviation use, Emergency Position-Indicating Radio Beacon (EPIRB) for maritime use, and Personal Locator Beacon (PLB) for personal use. Although Personal Locator Beacons (PLB) are designed to be carried by an individual, some are carried aboard vessels for users with both maritime and land capacity. From a design perspective, a PLB is a more compact personal unit which is registered to an individual. EPIRBs on the other hand, are registered to a vessel and have a longer battery life.

Currently, Galileo Return Link Service (RLS) is included in all beacon specifications, notably C/S T.001 (defining the minimum requirements for 406MHz distress beacons) and C/S T.007 (defining the type approval standard for RLS-enabled beacons). EUROCAE WG-98 will continue to develop Minimum Aviation Systems Performance Standards (MASPS) for ELT RLS, covering the function to trigger ELT transmission from the ground, and define high-level concepts and typical functional interface requirements between the ELT and the ground.

Although beacon specification activities are well underway, it is evident that a gap in product offering currently exists in the beacon market, triggering intense support from the GSA to accelerate the development of Galileo enabled SAR beacons with RLS for market availability by 2019. The GSA is committed to supporting the definition and development of second generation beacons by issuing funding to Horizon 2020 and Fundamental Elements projects, with the objective to increase the Technology Readiness Level of SAR beacons. For instance, the MESOAR Beacon prototyping grant awarded 2 aviation projects and 3 maritime projects (see next page) with the goal to develop, test and demonstrate the capabilities of Galileo-based MEOSAR maritime beacons with Return Link Service (RLS).

Global Aeronautical Distress and Safety System (GADSS)

GADSS is a concept of operations, developed by the ICAO working group (AHWG) which requests Distress Tracking capable devices by 2021. The GADSS concept consists of the following functions: 1) Aircraft Tracking, 2) Autonomous Distress Tracking and 3) Post Flight Localisation and Recovery.

Quoting the ICAO concept of operations, "This GADSS will maintain an up-to-date record of the aircraft progress and, in case of a crash, forced landing or ditching, the location of survivors, the aircraft and recoverable flight data". The ICAO SARPS on aircraft tracking, which establishes the tracking time interval of 15 minutes, will be applicable in late 2018. The GSA objective is to ensure that Forward Link and Return Link Services enable ELTs for Distress Tracking (ELT-DT).

Global Maritime Distress and Safety System (GMDSS)

In the maritime SAR sector, the International Maritime Organisation (IMO) is responsible for updating GMDSS, which is now being reviewed to include MEOSAR capabilities and enforce the use of Return Link capability for EPIRBs by Galileo Full Operational Capability. The next Maritime Safety Committee will provide feedback regarding this decision.

GSA' S SAR BEACONS PROJECTS LEVERAGE ON GALILEO RETURN LINK SERVICE

HELIOS

HORIZON 2020

The HELIOS project aims at providing second generation beacons and associated antennas designed to operate with the full capability of the new MEOSAR Cospas/Sarsat International Programme, embedded in the Navigation Satellite System of Galileo.

HELIOS' GADSS-compliant 'Distress Tracking-Emergency Locator Transmitter' (ELT-DT) allows a beacon to automatically send a distress signal, providing accurate position when it detects unusual activity, such as a precipitous drop in altitude. The capability to extend Galileo RLS capability is crucial to enabling distress tracking. By 2019, HELIOS will deliver an ELT, an Emergency Position Indicating Radiobeacon (EPIRB), a Personal Locator Beacon (PLB) and their associated antennas, all compliant with the Cospas-Sarsat international standards.

SAT406M and SINSIN

HORIZON 2020

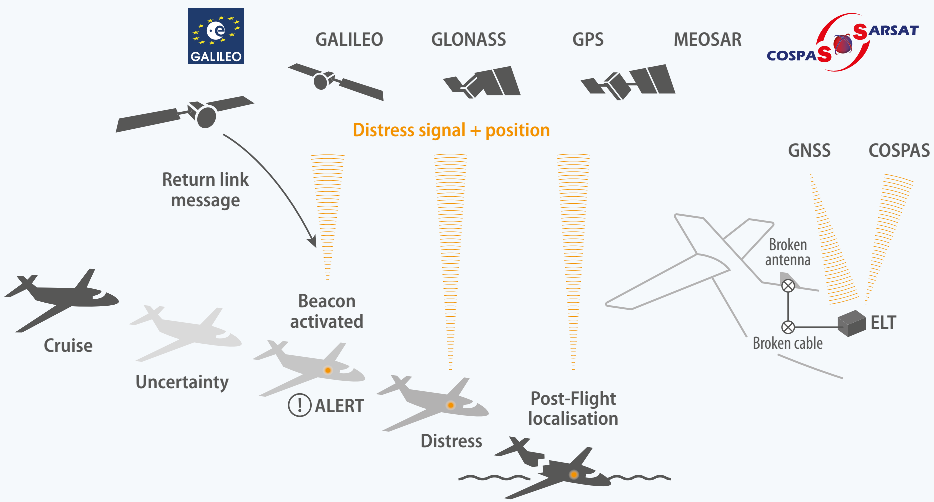
Ongoing GSA work for slow moving beacons detection involves the development of advanced algorithms to optimise Forward Link communication between Beacon and MEOLUT. A recent endeavour includes a Horizon 2020 project called SAT406M, which has investigated an E-GNSS application providing an end-to-end solution based on the Galileo SAR service using RLS. The project consortia have developed an RLS wrist-worn PLB prototype, which can transmit up to 10 extra bits of information in conjunction with MEOLUT capable of tracking 30 satellites. A similar project, SINSIN, explores an enhanced PLB with a Galileo enabled receiver, and a MEOLUT to improve the localisation of slow-moving beacons with restricted sky visibility.

© Mobit Telecom

GRICAS

HORIZON 2020

The GRICAS project developed a safety concept based on the use of Galileo SAR service including the development of New Generation Beacons, innovative MEOLUT that optimises the position accuracy for high dynamic beacons, a new RLS employment concept, and associated in-flight beacon activation triggers when detecting abnormal flight situations.



Fundamental Elements projects

Fundamental Elements

The **Cobalt** project (led by MRT) is focussing on the research, development and launch of a COSPAS/SARSAT compliant 406MHz PLB intended to be used in maritime.

The Maritime Rescue Unit will increase chances of location and survival by improving the relay time of the distress alert, increasing the signal location accuracy, improving the signal detection in difficult conditions, and providing user reassurance through RLS.

The **Phoenix** project (led by Ocean Signal) will encompass the design, development and manufacture of a 406MHz MEOSAR PLB aiming at accessing the benefits of RLS data encoded in the Galileo E1B navigation message.

The **Ametrine** project (led by Syrlinks) concerns the design, prototyping and certification of an ultra-compact SAR RLS first Generation Beacon aimed at the largest market penetration and dissemination. The radio module developed by Syrlinks will be adapted for this specific beacon featuring a new specific enclosure to reduce the risk of accidental alarm triggering, and integrating RLS status, to minimise the false alarms rate.

KEY PERFORMANCE PARAMETERS IN ALL TRANSPORT MODES BENEFIT FROM GALILEO AND EGNOS

Galileo

Safety- and liability-critical solutions require accurate and reliable positioning information, available in most of the situations. Used together with other GNSS, Galileo provides a major contribution in this regard. The higher number of available satellites due to the addition of Galileo significantly improves accuracy and availability of the provided location. This is of special relevance in challenging environments - such as urban canyons - mostly due to the density of tall buildings, which often block a receiver's line of sight to the navigation satellites. Galileo satellites also support the achievement of a faster TTFF.

Robustness is also improved by the addition of Galileo. On one hand, the addition of Galileo signals, data and frequencies makes spoofing and jamming easier to detect. On the other hand, Galileo's unique authentication features (NMA and SAS) ensure the signals have not been tampered with.

As a result, Galileo will contribute to estimating a location with sufficient reliability to be used to safety- and liability-critical applications such as connected vehicles and autonomous cars.

EGNOS

As with Galileo, the use of EGNOS in safety- and liability-critical solutions also provides a positive contribution in terms of accuracy achieved, thanks to the differential corrections broadcast. Nevertheless, the real added value of EGNOS consists in the provision of integrity and continuity, making it an essential addition to aviation and maritime solutions.

E-GNSS CONTRIBUTION TO KEY PERFORMANCE PARAMETERS

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

* The Key Performance Parameters are defined in Annex III
** ••• = major contribution, capable of enabling new GNSS applications •• = medium contribution, enhancing the user´s experience so benefits (e.g. operational or at cost level) are achieved • = minor contribution, performances improved but no major difference at users´ level.

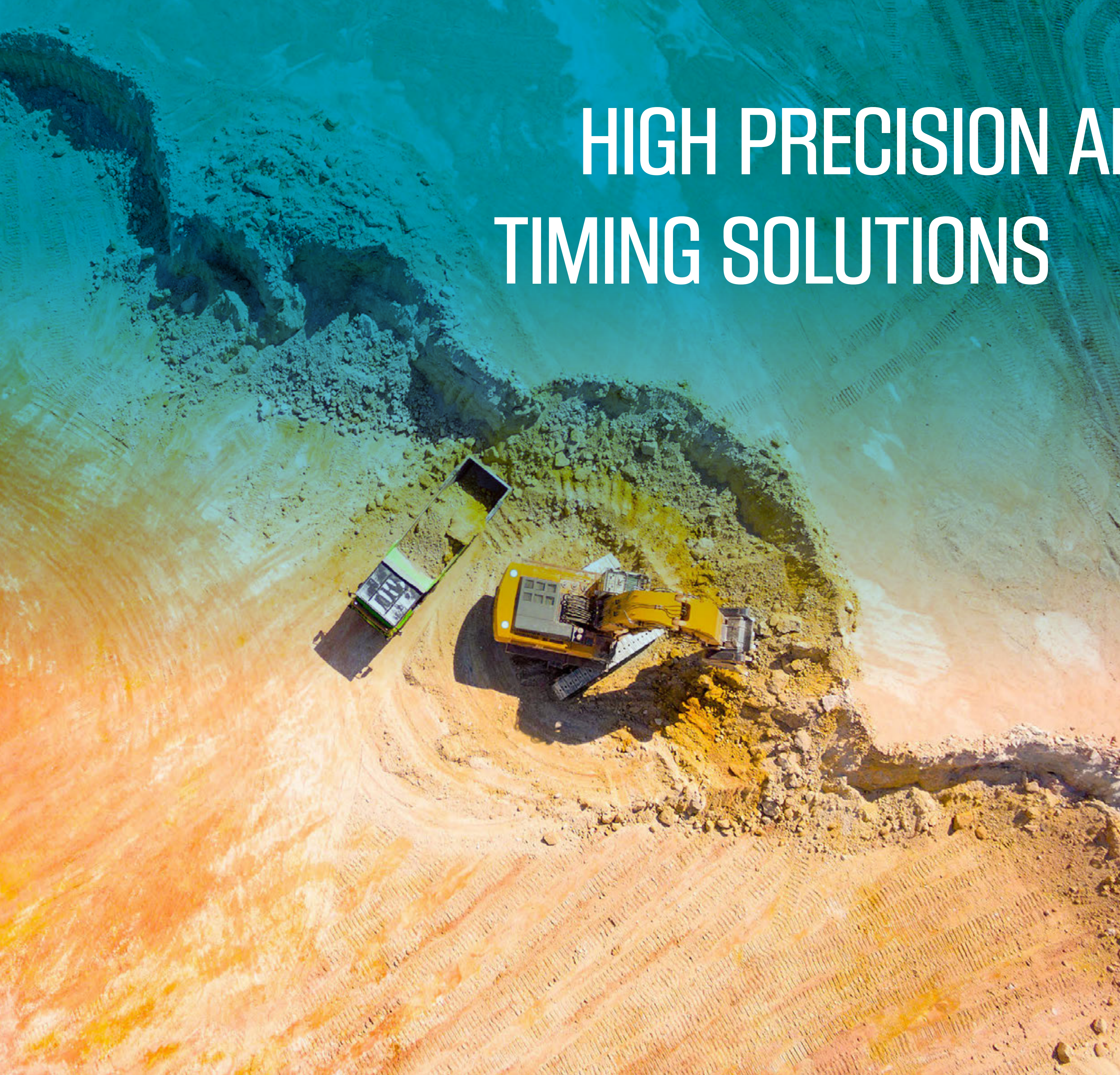
New GNSS solutions from STMicroelectronics for Automotive/safety and other segments

STMicroelectronics has introduced some new Galileo-enabled GNSS platforms:

- To extend its flagship Teseo-DRAW Automotive Navigation and Sensor fusion solution to target Highly Automated Vehicles, ST has launched the new TeseoAPP (ASIL Precise Positioning) GNSS multi-band receiver platform, compliant with ISO26262 Functional Safety requirements. The platform supports dual-frequency Galileo E1 and E5 signals, blended with all other legacy and modernised GNSS signals in conjunction with different GNSS Corrections systems, including the new Galileo High Accuracy Service. Implementing embedded authentication and anti-spoofing, the platform supports new liability-critical GNSS applications.
- To foster integration of the TeseoIII GNSS receiver, the Teseo-LIV3F GNSS module was introduced for mass market applications, providing Galileo-enabled multi-constellation positioning accuracy, supported by the popular STM32 Open Development Environment. The CLOE (Connecting and Locating Objects Everywhere) platform, co-developed by ST and Sequans Communications (www.sequans.com), was launched to support IoT applications using new LTE Cat-M and NB-IoT networks, pre-integrated with optimised firmware for low power flexible tracking.

Testimonial provided by the company

HIGH PRECISION AND TIMING SOLUTIONS



FAST, ACCURATE AND RELIABLE: THE DEMANDING REALITY OF PROFESSIONAL SOLUTIONS

Characterisation of the high-precision, timing and synchronisation macrosegment

From construction sites to vineyards, and from offshore surveying vessels to telecom networks, professional users are using GNSS solutions as their preferred option for high precision positioning and for accurate timing. Each constituent segment experiences different operational requirements and therefore relies on different performance parameters offered by advanced receivers.

Agriculture

GNSS is the key enabling technology helping farmers to increase the productivity and profitability of their agricultural activities and improve the management of their farms. GNSS also helps them to reduce their environmental impact and comply with the current legislative and regulatory framework. Through the provision of the precise location of farming equipment, and frequently combined with other technologies such as GIS, remote sensing (through satellites or drones) and machine vision, GNSS allows the accurate steering of tractors and the minimisation of pass-to-pass overlaps, the precise application of agricultural inputs at different rates throughout the field, and the retrieval of geolocalised data that can enable more efficient yield monitoring.

Surveying and Mapping

As advanced users of GNSS solutions, surveying and mapping professionals are benefiting from significant improvements in receiver technologies, such as higher availability of signals in the advent of the multi-GNSS era, falling prices and multi-usability. Several sectors including land surveying (cadastral, construction and mine), mapping and marine surveying (marine cadastre, hydrographic and offshore surveys) benefit from the spread of high-accuracy GNSS-based solutions. Multi-constellation and multi-frequency receivers, as well as various differential correction techniques (SBAS, RTK and DGNSS) and PPP, are currently the go-to option in the surveying and mapping sector.

Timing and Synchronisation

Telecom, energy and financial operators use GNSS as an accurate timing and synchronisation reference source. The telecoms industry is the largest user, and the ambitious plans for 5G technologies will require better synchronisation accuracy than ever before. New regulatory frameworks require financial operators to synchronise their computer systems, whilst energy networks will become more efficient through better synchronisation. A common driver for all applications is the need for more robustness and resilience.

Key performance parameters for high-precision

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

1. **Accuracy** requirements vary from metre, to sub-metre, to centimetre levels for different operations. It is achieved by deploying multi-constellation and multi-frequency receivers and utilising RTK, PPP, SBAS or combinations thereof. Certain agricultural activities (e.g. controlled traffic) require not only pass-to-pass accuracy but also year-to-year (GNSS drift).
2. **Availability** becomes 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 surveying 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).

Key performance parameters for timing & synchronisation

Besides accuracy, continuity and availability the most important parameters for timing and synchronisation are **Integrity** and **Robustness** in order to increase protection and resilience of the overall system against GNSS system fault, jamming or spoofing.

HIGH PRECISION AND TIMING KEY PERFORMANCE PARAMETERS

Key Performance Parameter (KPP)*	High Precision Solutions	Timing and Synchronisation Solutions
Availability	● High	● High
Accuracy	● High	● High
Continuity	● High	● High
Integrity	● High	● High
Robustness	● High	● High
Indoor penetration	● Medium	● Low
Time To First Fix (TTFF)	● High	● Medium
Latency	● Medium	● Low
Power consumption	● Low	● Low

● Low priority ● Medium priority ● High priority

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

HIGH-END PROFESSIONAL MARKET USERS ARE PUSHING THE LIMITS OF RECEIVER PERFORMANCE FOR THE BENEFIT OF ALL

HIGH PRECISION: LEADING COMPONENTS MANUFACTURERS

BDSTAR (UNICORE)	Asia-Pacific	www.bdstar.com
HEMISPHERE	North America	www.hemispheregnss.com
HEXAGON AB (LEICA, NOVATEL)	Europe	hexagon.com
HUACE (CHCNAV)	Asia-Pacific	www.huace.cn
JAVAD	North America	www.javad.com
JOHN DEERE (NAVCOM)	North America	www.navcomtech.com
SEPTENTRIO	Europe	www.septentrio.com
TOPCON	Asia-Pacific	www.topcon.co.jp
TRIMBLE	North America	www.trimble.com

TIMING AND SYNCHRONISATION: LEADING COMPONENTS MANUFACTURERS

BRANDYWINE COMMUNICATIONS	North America	www.brandywinecomm.com
FREQUENCY ELECTRONICS	North America	freqelec.com
FURUNO	Asia-Pacific	www.furuno.com
MEINBERG	Europe	www.meinbergglobal.com
MICROSEMI	North America	www.microsemi.com
OROLIA (SPECTRACOM)	Europe	www.orolia.com
OSCILLOQUARTZ	Europe	www.oscilloquartz.com
TRIMBLE	North America	www.trimble.com
U-BLOX	Europe	www.u-blox.com

High Precision

Professional users in the high precision segments have been early adopters of cutting-edge technological innovations, amongst which GNSS plays a pivotal role – both as a centrepiece of several current solutions and as a driver for their evolution. The most expensive and sophisticated solutions are first tested and adopted in high-end surveying applications, before being taken up in other markets once they become more affordable. This is further accentuated by the requirements of actors in capital-intensive industries (i.e. mining, oil & gas, and large-scale agriculture) investing heavily in the vanguard of technological development and driving the development of more advanced receivers (e.g. for machine control).

The high precision value chain consists of commercial augmentation providers, component manufacturers (receivers, antennas, integrated solutions, etc.), system integrators, and application or added-value service providers, serving a wide range of professional users who in turn work or are contracted by a number of end customers. Multinational companies with an established portfolio of solutions across various applications are leading the various 'links' of the global value chain. Amongst receiver and component manufacturers, the companies presented (table, left) offer a comprehensive suite of products serving the different high precision markets, including niche solutions. At the same time, network RTK services and commercial augmentation solutions (PPP and DGNSS) continue to proliferate.

Timing and Synchronisation

GNSS provides a unique offering to Timing and Synchronisation (T&S) user communities by delivering a free and highly accurate time and synchronisation capability available worldwide. GNSS has been rapidly adopted by the T&S user communities and in particular for critical operations, and is even considered as a breakthrough technology, especially for Telecom. Despite its long experience in GNSS, the T&S industry is still very active with many challenges ahead, linked to an increased need for reliability and security, supported by an evolution of the regulation and ever-increasing requirements by users in terms of accuracy, stability and reliability.

The T&S value chain is composed of GNSS chipset producers (who are usually generalist providers), GNSS Time product manufacturers (who add timing market specificities), equipment resellers (who may also provide design consultancy and maintenance/calibration services), system integrators (who integrate GNSS T&S equipment in complex networks), and network operators. The GNSS Time product manufacturers' industry landscape is composed of well-established international players proposing a wide range of products from OEM boards for commercial applications, up to high-end products for highly critical applications. Most companies presented in the table focus on specific market sectors such as telecom, energy, finance, transport, automation or military.

STRINGENT ACCURACY REQUIREMENTS ARE BEHIND THE WIDE ADOPTION OF MULTI-CONSTELLATION AND MULTI-FREQUENCY RECEIVERS

Multi-constellation adoption

Users across almost all applications in the high precision segments are actively seeking to gain from the benefits brought by the use of multi-constellation receivers. This includes increased availability (especially in attenuated environments, urban canyons or rural areas), faster ambiguity resolution, better coverage (especially relevant for northern latitudes), increased resilience (especially for Timing users), and improved satellite geometry. Thus, today the vast majority of receivers aimed at professional applications are capable of processing at least two constellations, whereas 40% can track four constellations.

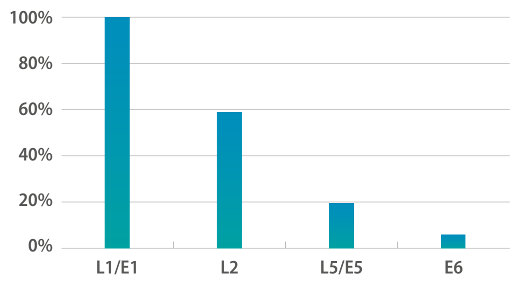
Multi-frequency adoption

The stringent accuracy requirements of several demanding applications (incl. automatic steering in agriculture and multiple surveying operations) can be met only by the use of multi-frequency receivers. This is achieved by removing the ionospheric error from the position calculation and effectively mitigating multipath. In a similar vein, the provision of Galileo E5 and GPS L5 as well as Galileo E6 has led to a proliferation of triple-frequency receivers, achieving a significant reduction in the convergence time for PPP and differential techniques. An additional benefit from the use of triple-frequency receivers lies in the increased protection against interference.

In the Timing segment, several GNSS Time products now offer dual frequency (with a current dominance of L1/E1 + L2 which should decrease towards L1/E1 + L5/E5 products). This is especially the case in the high-end solutions to improve accuracy and increase robustness. However, the penetration of dual-frequency receivers remains low, although growth is expected in the next five years.

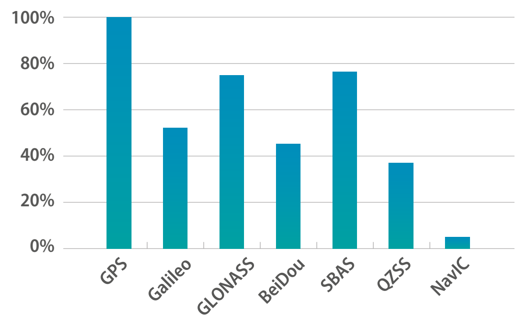
Today a continuously increasing number of receivers used in professional markets operates with triple-frequency capability (for example, over 20% receives L1/E1 + L2 + L5/E5).

Frequency capability of GNSS receivers[1]



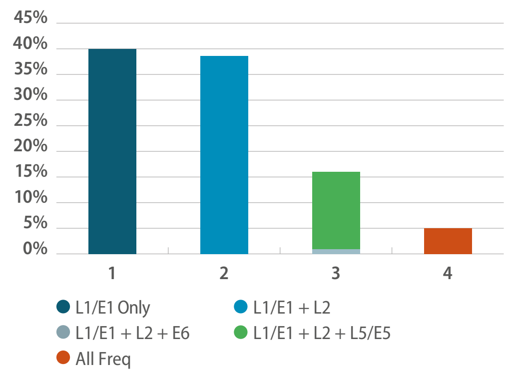
[1] shows the percentage of receivers supporting each frequency band

Constellation capability of GNSS receivers[2]



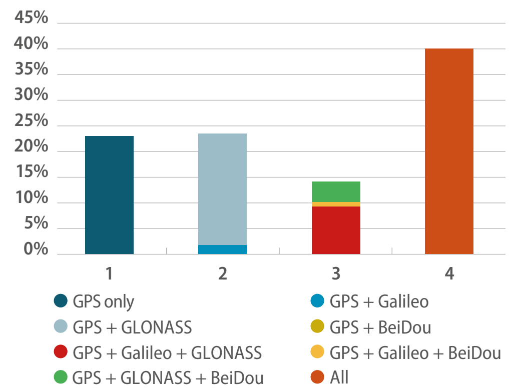
[2] shows the percentage of receivers capable of tracking each constellation

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 GNSS 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.

GNSS RECEIVER DESIGN SHAPED BY POSITIONING PERFORMANCE AND RECENT SEGMENT MODERNISATIONS

TYPICAL STATE-OF-THE-ART RECEIVER SPECIFICATIONS FOR THE HIGH PRECISION SEGMENT

Features	Surveying	Agriculture	GIS/Mapping
Number of channels	200-600	200-500	100-300
Observables	Code, code-smoothed phase and carrier phase		
Constellations	Multi-constellation		
Multipath rejection techniques	Usually yes	Usually yes	High-end models only
SBAS	Supported		
Receiver connectivity	Serial, USB, TCP/IP, Wi-Fi and Bluetooth ports, UHF and 3.5G radio modems, Serial Lemo, RTCM input/output	Wi-Fi, Bluetooth, 3.5G, NMEA, RTCM input, Serial Lemo/DB9	Wi-fi, Bluetooth, USB, 3.5G, NMEA, RTCM input
Multi-frequency	Yes	Usually yes	High-end models only
User interface	Hardware buttons, web interface, external controller	Hardware buttons, web interface, external controller	Hardware buttons, embedded virtual or physical keyboard
TTFF/TTC	RTK initialisation: < 10 s PPP convergence: < 1 min in selected regions, < 30 min worldwide	RTK initialisation: < 10 s PPP convergence: < 5 min worldwide	RTK initialisation: < 30 s PPP convergence: < 1 min in selected regions, < 30 min worldwide
Horizontal accuracy (95%)	Static: 2.5 mm + 0.5 ppm RTK: 8 mm + 1 ppm PPP: 4 cm DGNSS: 0.25 m + 1ppm SBAS: submetre	- RTK: 8 mm + 1 ppm PPP: 20-50 cm DGNSS: 0.25 m + 1ppm SBAS: submetre	- RTK: 1-2 cm + 1 ppm PPP: 10 cm DGNSS: 0.5 m + 1ppm SBAS: submetre
Vertical accuracy (95%)	Static: 5 mm + 0.5 ppm RTK: 15 mm + 1 ppm PPP: 9 cm DGNSS: 0.5 m + 1ppm SBAS: submetre	RTK: 8 mm + 1 ppm PPP: 9 - 20 cm DGNSS: 0.5 m + 1ppm SBAS: submetre	RTK: 4-5 cm + 1 ppm PPP: 20 cm DGNSS: 0.5 m + 1ppm SBAS: submetre
Form factor	Rugged smart antenna or modular unit with external antenna and remote controller	Rugged smart antenna, remote control box	Completely integrated handheld device
Antenna	Internal or external, active and passive supported	Internal	Internal or external
RTK readiness	All	Usually yes	High-end models only
PPP readiness	High-end models only	High-end models only	High-end models only

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

Receivers in this segment are designed to achieve various high precision levels

The form factor of receivers in this segment is determined by the optimal balance between functionality, weight, robustness, and cost. In addition, suitability of the receivers for their intended use is paramount, resulting in these identified four classes:

- **Static GNSS receiver** (2-3 mm) – developed mainly for post-processing of recorded static GNSS observations, which every chipset provides as a standard function (rarely – as an upgrade option). Additional form factors in this group are the provision of enough storage space, high capacity internal batteries, and the possibility to connect to external power supply and antenna. Static observation receivers, especially with modular design, are utilised almost exclusively in the surveying and GNSS infrastructure sectors.
- **RTK receiver** (8 mm to 2 cm in real-time) – dedicated for RTK/NRTK measurements. Receivers within this group are usually integrated and lightweight, equipped with compact internal and/or external datalink UHF/cellular modems, and are typically used in surveying, agriculture, construction, mapping and GIS. Most RTK receivers support static measurements as well, either as a standard or as an upgrade option. The integration of additional sensors (e.g. electronic bubble, tilt sensor) with the receiver-antenna body facilitates the operational and accuracy requirements.
- **PPP receiver** (5 to 30 cm in real-time) – a common receiver in the agriculture and marine sectors, but recently introduced in high-end chipsets for surveying, construction, mapping and GIS. The required accuracy level is achieved through the promising development of the real-time PPP technique. An important form factor is the integrated satellite L-Band and/or cellular datalink within the receiver.
- **DGNSS receiver** (30 cm and above) – typical for some agriculture and most mapping and GIS receivers.

Antenna designs incorporate several new strategies for maximum accuracy

Traditionally high-precision GNSS antennas are active and incorporate Low Noise Amplifiers (LNA) and coaxial connection ports to the receiver. The signal multipath mitigation problem is addressed through various proprietary techniques, providing either deflection or absorption of the multipath signal. The former strategy is common for choke ring antennas, while the latter is realised via special low power components. Support for the Galileo E6 Commercial Service signal is now featured in many new antenna models (and chipsets). To exploit the capacity of the Galileo E5 signals – which are on a wider bandwidth – a new trend has emerged across private and academic sectors. This entails the development of spiral GNSS antennas, which would be more appropriate for high-precision applications. Furthermore, additional filtering of near-band Iridium and Japanese LTE signals has recently been introduced. Another innovative feature is the integration of Analog-to-Digital converters inside the antenna body (Trimble DA1), which provides a new convenient type of connection via USB.

The channel-convergence connection

The proven relationship between the number of correlation channels and the speed of initialisation (RTK) and convergence (PPP) continues to dictate the GNSS ASIC chipset functionality. Very large scale integration allows a significant reduction in the energy per channel, thus chipsets with channels above 400-500 are becoming mainstream.

GNSS TIMING SOLUTIONS DEVELOPED TO RESPOND TO SPECIALISED DEMANDS

TYPICAL STATE-OF-THE-ART RECEIVER SPECIFICATIONS FOR THE TIMING SEGMENT

Features	GNSS Timing Board for Commercial Applications	High-end Timing GNSS Receiver for Critical Infrastructures
Dimensions	100 x 50 x 20	1 Rack Unit
Number of channels	Around 24 channels	More than 100 channels
Constellations	Two constellations (inc. GPS)	Multi Constellations
Frequencies	Single frequency (L1)	Single frequency (L1), some are multi-frequency
Time Accuracy	50 ns	50 ns
Frequency reference	Frequency Accuracy (24h avg.): <±1×10-12 Short Term Stability: <1×10-10 *	Frequency Accuracy (24h avg.): <±1×10-12 Short Term Stability: <2x10-11
Holdover	Basic holdover (OCXO) ±5µs over 24 hour	Full holdover (Rb) ± 1.1 µs over 24 hours
Output interfaces	10 MHZ, 1 PPS, NMEA, IRIG	10 MHz, 1 PPS, IRIG NTP, IEEE-1588v2 (PTP), SNTP
Operating temperature range	-40/85°C	-40/85°C
Antenna	External, active and passive supported	External, active and passive supported Smart antennas being developed

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

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GNSS Timing receivers can range from OEM boards for commercial applications to high-end final solutions in a chassis rack. Each solution is developed to ensure the optimum value proposal in a specific targeted market. There is therefore a plethora of equipment choice and the selection between the devices is usually a trade-off between accuracy requirements, holdover capabilities, interfaces and, of course, cost.

Accuracy level and holdover are critical aspects to consider when selecting a Timing solution

In nominal conditions with adequate access to GNSS signals, the timing solution can achieve around 50 ns time accuracy and ±1×10-12 frequency accuracy. In addition to the different dimensions, the high-end timing solutions and OEM cards for commercial applications propose distinct holdover capabilities. The holdover oscillator has a significant impact on the equipment performance, and therefore the price. A basic OCXO oscillator can run in holdover for 3-4 hours with acceptable performance, while an atomic clock can perform for up to 4-5 months, fulfilling for instance telecommunications` Primary Reference Time Clock (PRTC) specifications. The oscillator choice usually accounts for 10% to 50% of the total cost of the solution.

Interfaces and protocols influence the performance of the overall network

GNSS Timing receivers usually offer analog signal interfaces (10 MHz and 1 PPS), as well as serial interfaces. The most widely used interfaces are IRIG-B output or NMEA+PPS port, which provide accuracies close to 1µs but only for point-to-point connections.

Moreover, high-end GNSS receivers also offer Ethernet interfaces. In this configuration, GNSS receivers act as time providers and include network protocols to distribute time over Ethernet links. The main interest of this approach is that the GNSS Timing solution can distribute time over a large distance and to a large number of units. The performance is significantly related to the protocol used (SNTP, NTP or PTP), the network architecture, and the number of clients connected to the device. For instance, one NTP server can handle up to 100,000 clients.

THE SURVEYING SEGMENT BENEFITS LARGELY FROM THE MODERNISATION OF THE GNSS SIGNAL STRUCTURE AND CHIPSET DESIGN

The trends in survey-grade GNSS receiver design continue to follow closely the evolution of chipset technology, as well as the modernisation of all GNSS constellations. Several major benefits for surveying may be outlined.

Evolution of GNSS methods and services

All major GNSS survey component manufacturers are embedding the full GNSS frequency spectrum, including signals without publicly available Interface Control Documentation (e.g. BeiDou B3, GLONASS L3 CDMA and Galileo E6). This trend significantly benefits the Three Carrier Ambiguity Resolution (TCAR) and Extra-wide laning algorithms, which yield faster TTFF (RTK), faster convergence (PPP), and better ionosphere refraction elimination among other benefits. Component manufacturers are themselves becoming either PPP service providers, or team up with these, and consequently embed dedicated proprietary functionality in their chipsets (e.g. RTX and OmniSTAR – Trimble; TerraStar – Novatel, Septentrio, Leica Geosystems; StarFire – Navcom), thus providing an optimal combination of RTK and PPP in a single chipset. This approach is extremely practical for surveying in areas without sufficient cellular coverage (remote regions, border areas, etc.) where NRTK methods are not available, but a high-precision satellite L-Band correction signal provides an instant backup option for surveyors.

Benefits from optimised receiver form factor

The availability of channels, which some component manufacturers embed into their products, is now reaching over 400-500 for a single chipset – more than enough to support all current GNSS constellations and signals. Apart from the abundant channel availability, which is apparently well-developed now, standard high-precision chipsets provide connection to a single antenna, dual antennas for heading, or dual antennas + INS for full 3D positioning in dynamic or constrained environments. The majority of the rover surveying receivers are produced with built-in cellular internet functionality, which provide seamless access to NTRIP caster services, or RTK correction exchange via TCP/IP.

Recent developments in anti-jamming, interference detection and multipath mitigation provide additional benefits when surveying in dense urban areas with an abundance of unwanted near-band signals.

The major component manufacturers continuously develop better algorithms for multipath mitigation and continuous tracking during GNSS signal outages. Lowering the power consumption and extension of the product life cycle is yet another factor, pushing forward the design of survey-grade GNSS chipsets. With capacity of on-board data storage reaching up to 16-32 GB, static GNSS campaigns or other applications, which produce large amounts of data are more independent and secured against data loss.

Optimised user interface

Unlike several years ago, a user-friendly web interface console is currently provided by every major component manufacturer of GNSS OEM chipsets for the survey segment. This provides the ability to fully manage the receiver remotely, e.g. monitor its status, configuration, check for firmware updates, manage security access levels, and others. Some receivers have built-in cloud connectivity, providing seamless data exchange between field and office (via FTP push), and even password-secured anti-theft protection. Survey-grade receivers are frequently equipped with LINUX operating systems as a standard runtime environment. This provides many intelligent options, including operation via LED displays available in some smart antennas and modular receiver designs.

Enhanced multi-sensor integration

More and more manufacturers are integrating e-bubbles, inclinometers, gyro sensors and magnetometers in the receiver design, providing options for tilted measurements when necessary. Thus the capacity of many surveying applications has increased significantly, and as of recently can be even performed to the required accuracy in environments that were previously impossible, e.g. densely built urban areas.

Prices go down!

Pushed by the versatility of user requirements, the division between handheld, modular and smart antenna receiver design continues to dominate the GNSS survey market. The quality/price ratio is continuously improving however, especially with the emerging Chinese receiver manufacturers in the market. Full 3D positioning via GNSS+INS is becoming more and more affordable. Survey-grade GNSS receivers are now available at prices below €4,000. Moreover, the trend for many government-owned NRTK networks is the provision of unlimited high-precision services either for free, or at a low fee.

A GROWING POTENTIAL FOR HIGH PRECISION SOLUTIONS DELIVERED THROUGH MASS MARKET DEVICES

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The high-precision segment penetrates the cloud

Cloud-based GNSS data correction services, and the utilisation of Software Defined Radio (SDR) technology for mass market devices, are innovative multipurpose high-precision trends, which are a direct consequence of the evolution of the IT sector. A number of companies provide affordable high-precision GNSS correction services in the cloud, available either for professional or general devices. These services are referred to as Positioning-as-a-service (PAAS) and are realised in two general concepts:

- PAAS for professional GNSS receivers – the concept is applicable for segments such as mapping and GIS, surveying, and autonomous vehicles, etc. Data streams, consisting of DGNSS, NRTK, PPP or RTK corrections (depending on the subscription level), are input in a dual- or multi-frequency GNSS receiver. The resulting accuracy levels are down to 1 cm, albeit with variable initialisation times, depending on the quantity of the underlying GNSS infrastructure. As an example, SwiftNav Navigation introduced the SkyLark service in 2018, which provides the GNSS receivers of its proprietary vehicle with fast initialisation across several metropolitan cities in the USA.

- PAAS for mass-market devices – this approach utilises a mass market mobile device's generic motherboard via dedicated service apps, which basically transform it into a GNSS receiver, capable of receiving a cloud-based correction stream and performing baseband processing on the host CPU. In terms of speed, TTFF, noise, and other relevant parameters, the software GNSS approach is still inferior compared to the classic ASIC chipsets. However, the SDR technology is finally on the market, and aims to eventually replace the baseband processing done by the typical OEM chipset in fields like mapping and GIS, surveying, forestry, and many others. Such minimal cost, low power, software-based GNSS receivers are now available in the market, e.g. as developed by Galileo Satellite Navigation (GSN) for the Cadence Tensilica Fusion F1 digital signal processor.

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Trimble provides accurate positioning as a service

Trimble®

Pattle Delamore Partners Ltd (PDP) had a problem. As an environmental engineering agency in New Zealand, they work on projects of varying size, complexity, and sensitivity. Accuracy is crucial for their work. Relying on phone-based GPS is simply not reliable or accurate enough, but purchasing professional survey systems for their field crew was not cost-effective either. Hiring another company to do it may have solved the problem once, but they were undoubtedly going to have to face this issue again. They discovered Trimble Catalyst, a GPS receiver available as a subscription for Android devices. With Catalyst, they have been able to provide a low-cost, high-accuracy GPS solution to their field teams. They can quickly capture the data and precise measurements in the field and can scale the service up and down as their requirements change. Once a job is completed, the Catalyst subscriptions can be shut off and the antennas can be put on the shelf to wait for the next opportunity to be used.

For more information on Trimble Catalyst visit catalyst.trimble.com.

Testimonial provided by the company

NEW OPPORTUNITIES ON THE HORIZON THANKS TO UPCOMING FREE HIGH ACCURACY

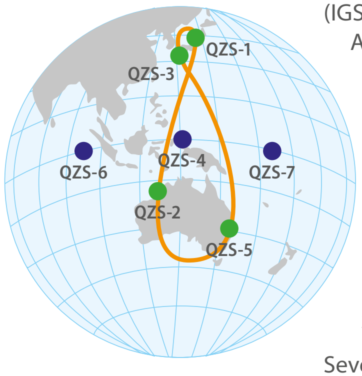
The evolution of GNSS-based solutions in the high-precision segments is driven by the demanding performance requirements, the increasing competition that puts signifcant strain on prices, and the need for integrated solutions that make the best of different technologies (incl. IMUs, LIDAR, etc.). Thus, users seeking decimetre to centimetre accuracy are primarily resorting to RTK solutions, or when these are not available (e.g. in marine environments or in rural areas lacking access to RTK networks) they turn to PPP. Recognising the importance of continuous access to high-accuracy solutions, the benefits of Galileo HAS from the offer of such a PPP-based service include:

- Receiver horizontal positioning accuracy of 20 cm.
- Global coverage, including high latitudes.
- Use of Galileo E6 data channel for augmentation message broadcast.
- Possible regional enhancement by ionospheric corrections to reduce convergence time.

The service will be provided for free, in line with the trend observed by national CORS networks in some EU countries or by regional systems (e.g. QZSS). This approach is expected to give rise to new opportunities for innovative services and business models.

QZSS starting the operational provision of regional augmentation services

With the launch of two satellites in 2017, the Japanese Quasi-Zenith Satellite System (QZSS) achieved the objective of a four-satellite constellation with the first fully operational services starting in 2018.



Three of the four satellites follow an inclined geosynchronous orbit (IGSO) that traces a north-south asymmetrical figure of eight. Although optimised for coverage over Japan, the orbit also covers parts of Australia at its widest arc, while its path narrows and virtually 'hovers' over Japan. The fourth, geostationary, satellite will augment the system and provide disaster messaging services.

The system transmits GPS-compatible signals (L1/L2/L5). Additionally, QZSS-specific signals are transmitted in L1, L5 and L6 to enable the Sub-metre Level Augmentation Service (SLAS) and - in L6 - the Centimetre Level Augmentation Service (CLAS).

Several application sectors are expected to benefit from QZSS services, including precision control of autonomous tractors in agriculture, machinery used in large-scale construction, and drones employed in delivering goods to the small islands of Japan.

Field Aware Navigation and Timing Authentication Sensor for Timing Infrastructure and Centimetre level positioning (FANTASTIC)

Fundamental Elements

FANTASTIC will deliver a further leap for high-precision GNSS applications at two levels simultaneously – receiver and antenna.

The GNSS receivers developed in the FANTASTIC project will bring several innovations in advanced GNSS tracking for interference and spoofing mitigation (both via OS-NMA and E6). Additionally, the FANTASTIC receiver will include sensor fusion for high-accuracy availability and resilience. The developed antenna will deliver increased availability of the high-accuracy measurements (by appropriate polarisation and space domain processing), as well as exhibit increased spoofing protection. Despite these features, the antenna will remain competitive from a cost perspective.

The receiver-antenna user equipment will leverage Galileo's differentiators for three concrete use case scenarios:

- Construction machine and tractor control – Galileo-specific signal features are exploited to enable the improvement of RTK availability and reliability, mainly in harsh environments where the received signal impairments can be mitigated.
- Trusted GNSS-based Timing for infrastructures - A first step towards secure commercial products will be made by implementing time authentication, as well as spoofing detection and mitigation algorithms based on Galileo's authenticated signals.
- Galileo HAS-based Precise Positioning-Innovations introduced in this project will be based on the processing of the Galileo high accuracy service which, with its enhanced navigation message, is expected to improve current PPP performance.

HIGH DEGREE OF SPECIALISATION IN PROFESSIONAL-GRADE RECEIVERS TO MEET DEMANDING REQUIREMENTS

Within the high-precision segment, a continuous trend for all component manufacturers is the provision and enhancement of specific solutions for every workflow, mostly by embedding and integrating common chipsets in a huge variety of designs, dedicated to different job aspects. Those solutions are mainly distinguished by specific firmware and software within versatile robust packaging.

Surveying

Solutions for surveying are typically characterised by a fully integrated design (receiver, antenna and controller) or smart antenna design (receiver and antenna only). Receivers are equipped with a multi-frequency, multi-constellation GNSS chipset, Tx/Rx internal radio and/or a cellular modem to receive/send (rover or base station) RTK/N-RTK corrections. Power is supplied through at least one rechargeable battery and in some cases external power supply. A current trend is the integration of additional sensors (e-bubble, inclinometers), which foster surveying productivity in the field. High-end surveying receivers are capable of dedicated PPP correction input (depending on the component manufacturer's strategy) via both IP and L-Band. On the software side, surveying GNSS solutions provide elaborate user-friendly functions for measurements, stakeout, and libraries with coordinate systems and datum transformations.

Agriculture

Agriculture is characterised by the utilisation of smart-antenna machine-control GNSS devices. High-precision capacity is provided by either single RTK base stations (usually of modular design), connection to CORS networks, or IP/L-Band, EGNOS and PPP services. Smartphone and handheld GNSS receivers play a complementary role, usually for field checks from metre down to decimetre accuracy. While the receiver design does not differ significantly from those in other segments (common chipsets are used with same multi-frequency and multi-constellation support, channel availability, etc.), the segment provides a vast variety of software solutions, developed specifically for every major task in the field – from land preparation, planting and seeding, to spraying, irrigation, harvesting, and water supply management among others. As cloud-based remote control of all GNSS receivers is essential to maximise field production, the trends in GNSS receiver design within this group is rich connectivity and communication functionalities.

Construction: engineering, machine control and marine

The major trend for all GNSS solutions within this group is the provision of full connectivity between all relevant workflow segments – field, machine/vessel, and office. Receivers are equipped with wide-range WiFi, cloud-based service management, and other connectivity services. The main receiver features are determined by the nature of the operating environment. Receiver are housed in metal (typically magnesium) cases that comply with the most stringent industry and military tests for vibration and water/dust protection. These rugged receivers are available as modular or as smart antennas.

Machine-control GNSS receivers are usually manufactured as smart antennas, supporting cabled connectivity with a controller inside the operator's cabin, from where manual or automatic hydraulic control over the machine's instruments is performed. Marine construction receivers are additionally characterised by some specific tasks, requiring real-time data transfer (usually via multiport output of NMEA-0183 and/or 1 PPS) to sonars, RF filtering of satellite phone signals (e.g. Iridium), which are a frequent reason for GNSS outages on vessels, and offshore-specific L-Band PPP services.

GNSS signal monitoring

Scientific applications for evaluation of the ionosphere and its negative effects on critical GNSS applications (e.g. aviation in areas close to the Earth's magnetic poles), especially during its recent active state (24th solar maximum), are fostering the development of specific GNSS architecture. Dedicated high-rate (up to 50 Hz) data logging, multi-frequency chipsets with amplitude and phase scintillation indices output, and Total Electron Content (TEC) monitoring capabilities are designed to meet the need of this small, yet important segment.

CORS networks

Receivers within this category typically have a modular design. A currently trending feature is the multi-channel, multi-frequency and multi-constellation GNSS chipset, integrated with the full variety of I/O formats and communication protocols available. The critical component is the multifunctional Ethernet, which usually supports Power over Ethernet (PoE), HTTP, HTTPS, TCP/IP, UDP, FTP, NTRIP Caster, NTRIP Server, NTRIP Client, Proxy server, Routing table, Email Alerts and File Push, Position Monitoring, and IP Filtering, among others. These features are of the utmost importance for the availability and reliability of the services of a CORS network, which are, in turn, utilised in surveying, construction, mapping and GIS, agriculture and others.

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INTEGRATION OF SOLUTIONS DRIVES THE PROFESSIONAL MARKETS

Combining the best of different technologies in a single solution

The need to perform complex, high-precision operations in diverse and often difficult environments has been driving the emergence of integrated solutions in the market. Thus, beyond making the best use of the possibilities arriving in the multi-constellation and multi-frequency context, several solutions rely on the integration of GNSS with other technologies (IMU, total stations, Lidar). In that regard, interoperability at hardware level is coupled with the ability to access the appropriate tool from a single software interface, thus allowing users to switch seamlessly (e.g. between GNSS and total station in topographic surveys, and stakeout at large construction sites). Integration with other sensors is also critical for hydrographic surveys since bathymetry is typically performed by multi-beam echo sounders (MBES) or Lidar, with GNSS providing the exact position of (the sensor on) the vessel or aircraft respectively, and INS providing its orientation.

All-in-one

A common trend across high-precision sectors is that of 'connected' operation, allowing a continuous communication and data stream between the manager's office and the in-field workers. Thus, managers of large agricultural holdings or construction and mining sites, or supervisors of marine operations and professionals responsible for GNSS/GIS-enabled asset management, require all-in-one solutions that enable monitoring, planning and decision-making towards increased productivity and cost-optimisation.

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From network to user

PPP-RTK solutions constitute an extension to the PPP concept by providing single-receiver users with information enabling the reduction of convergence times as compared to that of standard PPP. Thus, alongside precision satellite clocks, ephemeris and phase biases, PPP-RTK makes use of local/regional/national RTK networks to provide users with ionospheric and tropospheric delay corrections, allowing them to perform resolution of ambiguities and to achieve cm-level accuracy in significantly reduced time. This approach can benefit several application sectors in the high-precision markets, and therefore multiple solutions are currently under deployment, building on different methods.

Surveying hard-to-reach areas with drones

Surveyors have been quick in recognising benefits from the use of drones across a wide range of surveying activities. Their use is generally considered a low-cost, high-yield solution that enables:

- **Increased access to areas that are hard to reach by other means.** This applies to areas with complex topographical features, which can be accurately mapped using drones equipped with Lidar or other optical sensors.
- **Significant reduction of surveying time.** Drones gather data from the sky - in the form of geo-referenced digital aerial images taken from different angles. When equipped with survey-grade GNSS RTK receivers, drones are effectively acting as flying rovers receiving corrections from the base station, and collecting vast amounts of highly-accurate data in a very short timeframe (as compared to conventional ground methods).
- **Collection of vast quantities of data.** Drones can rapidly collect millions of data points with a resolution as sharp as 1.5 cm per pixel. Moreover, drone-mounted cameras can produce continuous filming footage. The collected data can be issued digitally within a few hours after the survey or, if required, downloaded while still on site.
- **Reduced health and safety risks** by minimising the need to expose surveying personnel to dangerous locations (e.g. unstable slopes, transport routes, etc.)

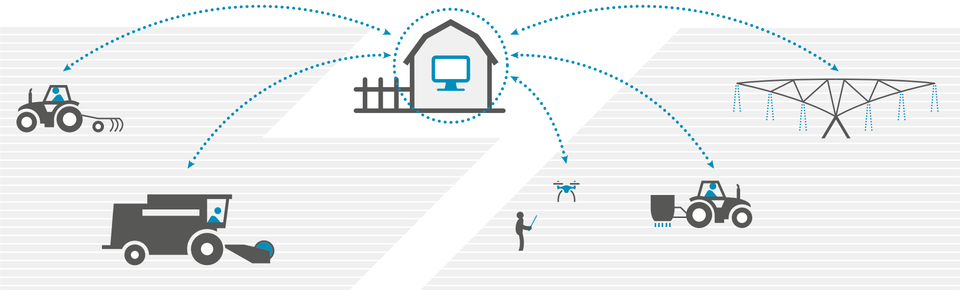
GNSS LIES AT THE CORE OF SMART, CONNECTED AND INTEGRATED AGRICULTURE SOLUTIONS

Faced by continuously growing demand, scarcity of resources and climate change, agriculture is relying more and more on **smart, connected and integrated solutions**. This paradigm shift, heralding the advent of *Agriculture 4.0*, is driven by the increased ability to collect large amounts of data and turn it into informed decisions within an **integrated farm management** approach. Thus, by making use of advancements in Big Data Analytics, IoT connectivity, sensing capabilities (via satellites, drones or proximal sensors) and robotics, farmers gain an unprecedented level of knowledge about their crops, livestock and operations. The 'site-specific' dimension of this approach is enabled by GNSS, which enables geolocation of the collected data, precise guidance of the machinery and tracking in a 'farm-to-fork' context.

In that regard, GNSS presents an invaluable component of integrated solutions, driving the digital revolution in agriculture, supporting the implementation of key regulatory measures (i.e. Common Agriculture Policy - CAP) and allowing farmers to make their activities more profitable, efficient, safe, and environmentally friendly.

Everything connected!

IoT technologies are transforming the agricultural world. By enabling the collection, processing and analysis of large amounts of georeferenced, site-specific data, they facilitate the provision of smart solutions designed to provide decision support. This is powered by the proliferation of Big Data analytics on the cloud, fast internet everywhere, and advanced inter-connected sensors. (Near) future farming will see farmers accessing and cross-analysing weather, crop or operations-related information and, eventually, managing their entire agricultural holding on a computer or mobile device. Data-enabled agriculture is currently the top priority amongst investors, and further supported by major Pan-European initiatives such as Internet of Food and Farm 2020.



Seeing more, knowing more and acting more efficiently

The use of remote (and proximal) sensing methods in support of precision agriculture has a long history. Its impact however in terms of providing timely and accurate information on several aspects related to agricultural production has been growing continuously. This is owing to:

- The availability of 'Big Data from Space' – spearheaded by **Copernicus' free, full and open data policy**, and by the **emergence of new EO business models** relying on large fleets of small satellites (e.g. Planet) covering every spot of the Earth daily.
- The increased **investment in drone technologies and the relaxation of the regulatory framework**, enabling them to become a viable tool deployed throughout the crop cycle.
- The **increased availability of hyperspectral cameras** developed for agricultural activities, which – through advanced machine learning capabilities – can detect features that no other image and certainly no human eye can.

Thus, traditional value chain players and fast-rising venture-backed start-ups are providing farmers with services that rely on hyperspectral, multispectral or thermal sensors to identify exactly which parts of a field lack water or need improvements. Additionally, once a crop is growing, several solutions allow the calculation of the vegetation index, show the heat signature and allow crop planting. In all these applications, GNSS is a crucial component as it allows georeferencing of the collected data, high accuracy of operations, and even the realisation of profitable business models (especially when considering drone-based services in the Beyond Line Of Slight context).

The future is happening now!

As the agriculture sector strains to produce more with fewer resources, the need to embrace the latest technological trends has led to the emergence of disruptive approaches. Some of these, even if not fully mature, have been attracting significant amounts of venture capital – often in conjunction with favourable policy priorities – and are thus worth keeping an eye out for:

- **Blockchain***, especially when paired with IoT technologies (involving sensors, RFID tags, or GNSS authentication) can enable improved product tracking and transparency in supply chains (e.g. in relation to genetically modified and antibiotic free food), but also decrease transaction fees in the farming context.
- **Nanotechnology-driven precision agriculture** involves the utilisation of nanoencapsulated conventional fertilisers, pesticides, and herbicides in order to release nutrient and agrochemical dosages in a precise and sustained manner.

* A blockchain is a digitised, decentralised and distributed list of records – called blocks, which are linked and secured using cryptography.

AUGMENTED REALITY ADDS VALUE TO THE WORLD OF HIGH PRECISION

Augmented Reality (AR) has many useful applications, particularly in city planning, construction and mining. In the high precision market, GNSS receivers already meet the key performance parameters required to enable AR. Just as positioning performance can be improved by external data, the usefulness of external data can be enhanced by accurate positioning.

In **city planning**, AR enables project stakeholders to see how a building design will look in its actual location. During implementation of the project, AR can be used to allow incremental refinements. This is achieved primarily through visualisation of building models in-situ.

In construction, AR permits the overlay of schematics on existing buildings. It also helps project managers to see how everything fits on site before parts are ordered or assembled, thus preventing errors and reducing costs. Furthermore, AR can drastically improve stakeholder engagement as a tool to showcase what it is being built (presenting the end-product) and how the structure will benefit or impact its surroundings. In this context, a growing number of companies are developing their own wearables to support AR applications in construction. This has given rise to **mixed reality** (MR) solutions – an advanced form of AR – blending real-world objects with digital content, interactively, and in real-time. In this case, different vendors are offering solutions in conjunction with Microsoft Hololens – the most popular wearable.

In **mining**, an early adopter, the application of digital-data visualisation into the real world can improve productivity, safety and even machinery uptime. Mining industry pioneers are using AR/MR solutions in several aspects of mining operations; from defining the mining area, to environmental licensing scenarios, and even closure of a mining site.

Future first person view (FPV) drones will show more than just video

AR applications relying on the highly accurate position and timing information made available by modern GNSS solutions are also making their way into the world of drones.

This includes, for example, solutions whereby virtual content is integrated in real time into video feeds provided by drones. Such technology can have important practical applications. Among others, it can be used to visualise the **impact of future buildings** on the landscape or for the **training** of drone operators, who will be able to practice delicate manoeuvres using actual drones but in safe environments. In operation, it will allow the display of data such as airspace restrictions.

In more operational contexts, AR solutions are benefitting from the fusion of data from multiple sensors (e.g. advanced thermal cameras) that ensure drone operators have access to information that is not available in the visual spectrum. In this regard, a prime example is firefighting where AR is used to superimpose critical data over the video image, such as high-resolution digital terrain models and a 3D hologram of the fire. Another example is **disaster response**, where information overlaid via AR onto drone-captured video of flooded areas can help more effective response or relief activities.

LARA

LARA HORIZON 2020

Powerful and affordable mobile computing devices combined with cheap dual-frequency chipsets developed for the mass market are blurring the lines between professional and consumer devices. LARA – the LBS Augmented Reality Assistive System for Utilities Infrastructure Management through Galileo and EGNOS – has been working on the development of a new mobile device that provides field workers in underground utilities with the ability to 'see beneath the ground'. The device combines GNSS technology (Galileo and EGNOS), 3D GIS technology, and geospatial databases with computer graphics and Augmented Reality in order to render complex 3D models of underground networks – be it sewage pipes, gas conduits or electricity cables. The project was concluded in 2017; its outputs are now being commercialised through the implementation of the corresponding business plan.

GIS GRADE RECEIVER TESTING CAMPAIGN YIELDS POSITIVE PRELIMINARY RESULTS

Approximately one year after the declaration of Galileo Initial Services, the GSA opened a call for interest in a testing campaign of **GIS grade receivers**. Several manufacturers expressed their interest and are participating. The testing campaign, using live signals, will continue until the end of 2018.

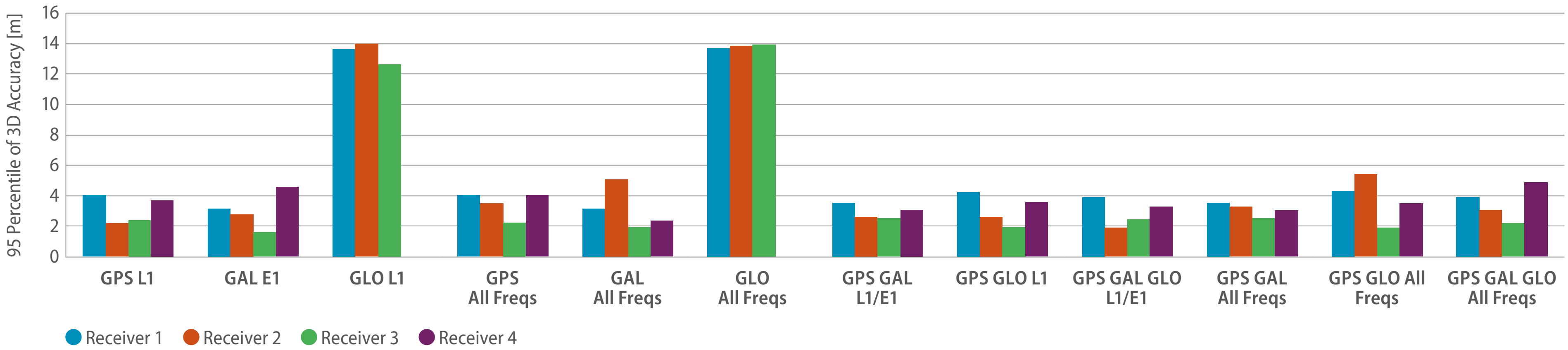
The objective is not only to evaluate the performance of the receivers, but also to assess the added value of Galileo through testing different receiver configurations (from singe constellation, single frequency to multi-frequency, multi-constellation, combined with RTK or DGNSS) in different environmental conditions.

The final goal is to properly estimate specific Key Performance Parameters commonly used by the GIS community, such as **Positioning Error** and **Time To First Fix**.

The results available so far are summarised in the figure below. The data have been collected in an "open sky" scenario in static mode, single point positioning (RTK and DGNSS yet to be run), at medium latitude (Rome) and with a very mild ionospheric activity. As a consequence, the expected added value of multi-GNSS cannot be evidenced (open sky), and neither the advantages of an ionosphere-free solution (low ionospheric activity), nor those of the high E5a/L5 chipping rate (low multipath) are visible. Rather, these results evidence between receivers differences as large as between configurations differences, so that no conclusion can be drawn on these questions. However, they already show that, although the Galileo constellation is not yet fully deployed, **Galileo accuracy performance achieves GPS levels**, both in single and multiple frequency cases.

More challenging scenarios - Urban and Under Tree Canopies - are under assessment, and preliminary results confirm that multi-constellation (GPS + Galileo) accuracy outperforms single constellation (GPS only) accuracy. Regarding the ionospheric errors we do not expect any significant change of the situation, so the analysis of multi-frequency data sets will focus on E5a/L5 multipath discrimination capability and how various receiver models benefit from it.

OPEN SKY SCENARIO: 95 PERCENTILE OF 3D ACCURACY PER RECEIVER



Tests in the field are performed in different scenarios.

Open sky

Under tree canopies

Urban

In an OPEN SKY environment, Galileo-only acquisition and accuracy is as good as GPS-only.

ACCURACY AND RELIABILITY DRIVE TIMING DEVELOPMENTS

Providing ever better timing performance

Even if GNSS receivers already provide very high-performance timing and synchronisation solutions, improving accuracy remains a continuous challenge for manufacturers; precise calibration of the antenna position is used to improve timing accuracy, the possibility to compensate antenna cable delays, through receiver configuration, is proposed, and algorithms are implemented to reduce time-pulse jitter. All these improvements allow smoother and more accurate timing solutions from GNSS, even in single frequency.

Whilst many receiver manufacturers now propose multi-constellation capabilities (GPS, Galileo, GLONASS and BeiDou) to improve availability and reliability, the provision of dual-frequency GNSS – although currently marginal – is also increasingly considered not only in the high-end timing receiver market, but also in medium-end receivers to eliminate ionospheric effects. To limit the impact on receiver costs, some manufacturers also work on innovative solutions to minimise ionospheric effects in single-frequency, such as NeQuick model implementation.

Improving protection against failure

In January 2016, a software upload to US GPS satellites induced a 13-microsecond misalignment in timing. This seemingly insignificant difference was far greater than the maximum tolerance for error in many applications, and resulted in loss of synchronisation in several systems, including power grids and financial institutions. The need to protect receivers against these types of failures is therefore driving the development of Advanced T-RAIM algorithms, and the implementation of SBAS such as EGNOS, which remained stable and properly synchronised to UTC during the 2016 GPS anomaly.

Towards more traceability

There exists an increasingly strong market demand for traceable and certified time. Formal traceability to UTC and timing liability, however, cannot be ensured by GNSS receivers only, with the unique recognised providers of legal time being the National Metrology Laboratories (NMIs) participating in the UTC calculation performed by the BIPM. Nevertheless, in order to meet the demand of several users such as the finance industry, various initiatives have been launched to provide Time-as-a-service, promising Time traceability and certification such as NPLTime or DEMETRA. These solutions rely on several complementary techniques including GNSS.

More info is available from: www.npl.co.uk/commercial-services/products-and-services/npltime and from: www.demetratime.eu

TYPICAL HOLDOVER CAPABILITY OF TIMING RECEIVER USED IN CRITICAL INFRASTRUCTURE

Oscillator Maintaining <1msc	3 mins	3 hrs	3 days	3 wks	3 mths	3 yrs	> 3 yrs
TCXO	● (green)	● (amber)	● (red)	● (red)	● (red)	● (red)	● (red)
Low Spec OCXO	● (green)	● (green)	● (amber)	● (red)	● (red)	● (red)	● (red)
High Spec OCXO	● (green)	● (green)	● (amber)	● (red)	● (red)	● (red)	● (red)
Low Spec Rb	● (green)	● (green)	● (green)	● (amber)	● (red)	● (red)	● (red)
High Spec Rb	● (green)	● (green)	● (green)	● (amber)	● (red)	● (red)	● (red)

Source: K. Kovach et al., "GPS Receiver Impact from the UTC Offset (UTCO) Anomaly of 25-26 January 2016", ION GNSS+ 2016, Portland, Oregon.

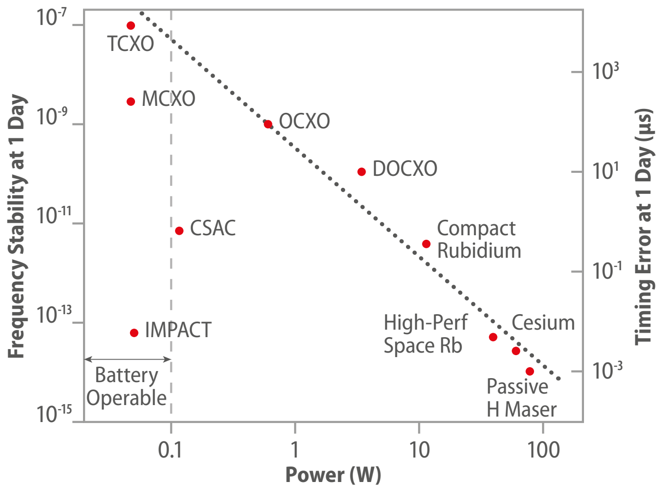
The other side of the T&S receiver story is the local oscillator, which is specified to match the time and phase of the reference (master) oscillator (i.e. steered by GNSS). The local oscillator determines both the time precision that the receiver can achieve, and the length of time it can operate without GNSS signals (holdover time).

Many developments for smaller and stable oscillators

Local oscillators strongly affect the cost of the receiver and are built around two technologies: atomic and crystal. Atomic oscillators typically have several orders of magnitude less uncertainty than the cheaper crystal oscillators. Uncertainty is typically expressed both in terms of short term stability and the longer term 'ageing rate', which results in the requirement to regularly synchronise to GNSS. Atomic clocks are historically very bulky and consume a relatively large amount of power (typically designed to fit in computer server racks). The recent development of commercially available chip-scale atomic clocks therefore provides a compelling option for applications that demand high timing accuracy or holdover capability, a small form factor and low power consumption. This is vital for robustness as interference for example, can be addressed by entering holdover, but only if the oscillator provides sufficient accuracy for the application's requirements until the interference has passed. At the other end of the size and power consumptions scale, current research and development into optical clocks, and using lasers to cool atoms, promise the potential for reducing the uncertainty by further orders of magnitude.

OSCILLATOR PERFORMANCE VS. POWER

Source: Chip scale atomic clocks, Svenja Knappe, NIST



CRITICAL INFRASTRUCTURE APPLICATIONS REQUIRE MORE RESILIENCE TO MITIGATE SECURITY THREATS

Precise time is crucial to a great variety of economic activities worldwide such as communication systems, electric power grids, and financial networks. Increasing robustness of these systems is therefore high on the agenda of the GNSS Timing industry.

GNSS Timing receivers are increasingly designed and built for robustness

The first level of defence against GNSS threats is ensured by implementing best practices at receiver level. Protection against jamming is provided by several interference detection and mitigation solutions, often based on proprietary solutions, such as notch filters or wide band interference monitoring. Even if more recent, the development of solutions to provide robustness against spoofing is also becoming the norm; it includes constellation and frequency agility, the use of an advanced T-RAIM algorithm (or Time Synchronisation Attack Rejection and Mitigation – TSARM), but also signal processing techniques (e.g. C/N0 monitoring, time jump monitoring). Active antennas with selective angular steering patterns are also increasingly considered for both jamming and spoofing mitigation. Once jamming or spoofing are detected, a good holdover capability is crucial to provide resilience.

Networking can help to mitigate cyber security threats

Network capabilities can be used to complement the strengthening of the whole system. For instance, a network provides point-to-point comparison with another external source. Moreover, network hierarchy can be used to re-route synchronisation or make a decision to maintain an isolated sub-network.

Galileo-based synchronisation for critical infrastructure

For many critical infrastructures from different industry sectors like telecoms, power, finance, broadcasting, defence and traffic/transportation, Meinberg's GNS181 receiver is a powerful and reliable time and frequency synchronisation solution. The GNS181-based clock module can use up to three different GNSS constellations in parallel, supporting Galileo, GPS, GLONASS and BeiDou. It is fully compatible with Meinberg's Intelligent Modular Synchronisation (IMS) product family. The IMS-GNS181 clock module can easily be added as a second, redundant clock module to an already deployed IMS system or can replace an existing clock module as the primary source of time and frequency.

The IMS platform makes it possible to combine a large number of input and output cards with the GNS181 receiver, allowing the use of Galileo as a time and frequency synchronisation reference in many different environments. Different chassis form factors share the same modules and make it possible to adapt an IMS system to fulfil almost any synchronisation requirement, regardless of application.

Testimonial provided by the company

Orolia-Spectracom adding resiliency to Time Sensitive Networks (TSN)

Time sensitive networks (TSN) use an enhanced data link layer to minimise latency and uncertainty in time transfer and time stamping of data and events to process critical information. It nurtures the exponential development of digital economy.

GNSS is the most widely spread source feeding TSN through IEEE 802.1AS using Precise Time Protocol. GNSS timing receiver are the key interface between the external world and TSN. Galileo is the easiest, most accurate way to access public and traceable timing source for critical TSN.

Timing GNSS receiver must detect and manage GNSS signal disturbance. Orolia-Spectracom, as a leader in critical infrastructure timing solutions, has included in their GNSS receivers BroadShield, a smart threat detection algorithm able to notify the network operator of jamming and spoofing. Mitigation action can be automatically engaged to switch over other external timing sources such as LORAN, Low Earth Orbit STL service or rely on an embedded high performance oscillator. BroadShield is also ready for the forthcoming Navigation Message Authentication service that will be a unique feature delivered by Galileo.

Orolia-Spectracom timing products are benefiting from such resiliency to provide TSN timing you can trust.

Testimonial provided by the company

EUROPEAN GNSS BOOST HIGH PRECISION APPLICATIONS PERFORMANCE

Applications included in the "high-precision and timing solutions" macrosegment are the most demanding from a performance viewpoint. There is therefore a strong willingness from users to employ new technological solutions able to ease their professional activities, while technology providers are continuously innovating to differentiate their products. From this perspective, Galileo and EGNOS represent a key differentiator to improve accuracy, availability, integrity, resilience and robustness.

In terms of accuracy, Galileo will support demanding users through the delivery of the Galileo HAS. Thus, the Galileo HAS - provided free of charge – will deliver PPP corrections globally via E6 (no additional communication channel needed) and its triple frequency will enable faster convergence time, thus shortening the time needed to get a first accurate fix. Additionally, users will benefit from using the E6B signal for tri-laning, allowing for greater reliability and enhanced accuracy. For timing users, the addition of Galileo satellites will contribute to ensuring that the most challenging requirements in terms of accuracy are met, including 5G requirements.

The addition of Galileo satellites to the ones tracked by multi-GNSS receivers also enhances service availability. This is especially useful in difficult environments where fewer satellites are normally visible. Furthermore, by leveraging full E5 AltBOC, the multipath rejection will be improved as well as the performance under tree canopy. For timing applications, this is of special relevance, since the addition of Galileo would improve integrity and ensure availability of the Timing Service should other GNSS experience major outages.

Robustness is also enhanced by Galileo; its authentication features will help mitigate external threats such as spoofing. Especially as the Galileo SAS will include the first-ever GNSS spreading code encryption capability for purely civil purposes, increasing the security of professional applications by giving users confidence that they are using signals and data from actual satellites, and not from another source. This is of special interest in the timing & synchronization domain, since it may enable the development of innovative applications, including based on time stamping.

EGNOS on the other hand has already proven its usefulness among professional users, owing to its capability of providing an affordable and easy-to-use solution offering the sub-metre accuracy needed to support many entry-level applications, such as mapping and precision farming. Finally, EGNOS integrity fulfils the user need of understanding the degree of fidelity of a measurement, by adding a level of confidence to the positioning and timing information provided.

E-GNSS CONTRIBUTION TO KEY PERFORMANCE PARAMETERS

Key Performance Parameter (KPP)*	EGNOS contribution** [High precision/Timing and Synchronisation]	Galileo contribution** [High precision/Timing and Synchronisation]
Availability		●●●/●●
Accuracy	●●/	●●/●●
Continuity		●●●/●●●
Integrity	●●●/●●●	
Robustness	●●●/●●	●●●/●●●
Time To First Fix (TTFF)		●●/

* The Key Performance Parameters are defined in Annex III
** ••• = major contribution, capable of enabling new GNSS applications •• = medium contribution, enhancing the user´s experience so benefits (e.g. operational or at cost level) are achieved • = minor contribution, performances improved but no major difference at users´ level.

EDITOR'S SPECIAL: AUTOMATION

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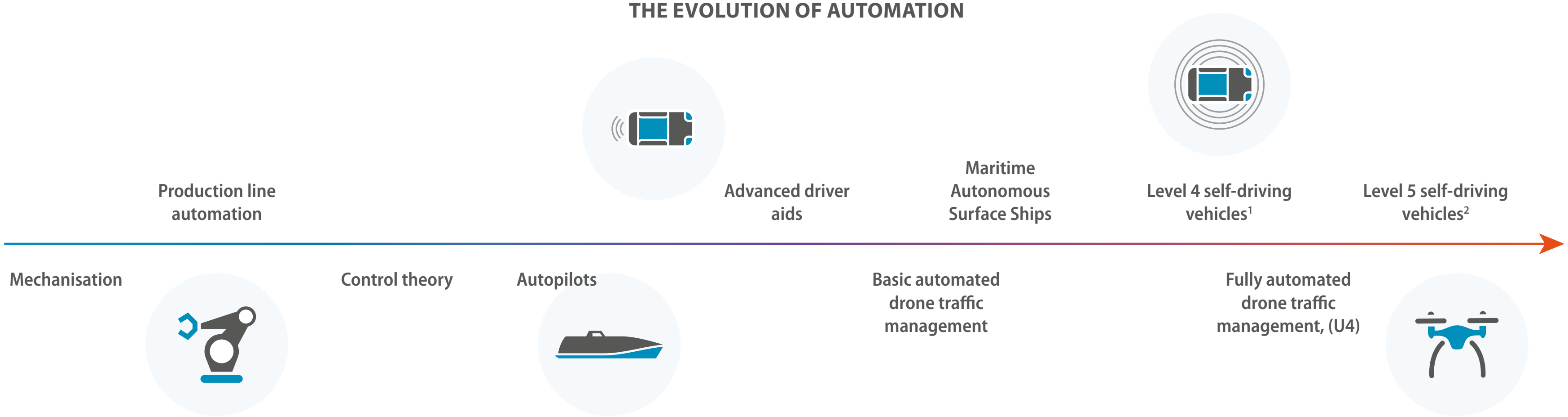
GNSS WILL BE A CRUCIAL SENSOR IN THE AUTOMATED WORLD

Whilst automation may seem like a new phenomenon, it has a long history; indeed the concept of an automaton and even the word itself originated in ancient Greece. Automation deals with controlling systems and performing tasks automatically, i.e. without human intervention. Throughout the ages, advances in automation have provided huge leaps forward in the quality of human life, ridding mankind of difficult, dangerous, or tedious tasks. Today we are entering a new era where automation will not only take on simple tasks performed in a well-defined context, but will be applied to increasingly complex tasks performed in a changing environment, including 'safety-of-life' applications such as autonomous operation of unmanned vessels, cars or flying taxis. Automatic controllers need system state/output information available from different sensors to provide commands to actuators, which act upon the system to drive it towards its desired state. GNSS will be a crucial sensor in the automated world, whether for synchronising sensors, as the primary positioning sensor for automated transport, or as a tool to calibrate other data sources. GNSS will be a known quantity in an increasingly complex world of sensors and processing.

THE EVOLUTION OF AUTOMATION



Key performance requirements

To deliver the required safety, **integrity** – detecting and alerting if a system has failed to meet the required accuracy – is the first performance parameter. In future automation applications, however, this will not be sufficient; a fully self-driving vehicle typically cannot abandon its procedure (e.g. a plane landing) when a fault is detected, rather the system must be able to adapt and take adequate measures to minimize the overall impact on safety. Parameters such as **continuity** play a role in ensuring that performance is still met for the complete duration required by the application. This must be the case even in the presence of interference or spoofing; this is referred to as **robustness**. In future, the user experience will need to provide seamless performance during transition between environments (such as leaving a tunnel).

The next most important parameter is **availability**. To succeed, automated systems must match or exceed the capability or performance of existing systems. If there are limits on when or where a system can function this would not be achieved.

Finally, **high accuracy** is required in most automation applications. For example in the case of an autonomous vehicle, it is not sufficient to know which road the vehicle is on as the lane it occupies must also be known.

Assurance demanded

Integrity alone will not allow automation to be realised or, more specifically, to be approved. For that, the performance in terms of navigation and time must be **assured**. This means dealing with both unintended and malicious interference to ensure **security** (especially cybersecurity) as well as **safety** in the context of an overall solution.

Discussing the case of a marine system responding to a spoofing attack, it has been stated that "the appropriate figure of merit is the *Integrity Risk (IR)*, i.e. the probability of the ship's position error exceeding a given alert limit, without raising an alarm[3]."

This statement equally applies to other contexts. Approaches to solving this problem focus on processing independent data from different and redundant sources to form-fused PVT solutions, and on evaluating the level of trust which may be placed on them, combined with some external knowledge (for example map data and historical data).

1 Fully autonomous safety-critical functions, with limited operations (not all scenarios)
2 Fully autonomous system with performance equal to that of a human driver in every scenario
3 Todd Humphries, "Assured Navigation and Timing" ION GNSS17-0213

GNSS AND AUTOMATION ARE MUTUALLY BENEFICIAL

Some automation needs can be satisfied by augmented GNSS alone. For example, the most stringent aviation Required Navigation Performance (RNP) standards are met by GNSS. These standards must be met autonomously by the Flight Management System to provide the predictability needed for future operational concepts to be achieved.

Automation in need of timing and synchronisation

Controllers need inputs from sensors to assess the state of automated systems and send commands to actuators. The more complex the system is, the higher the diversity and quantity of the sensors. Data from these sources must be properly synchronised or time tagged to be used together, and GNSS is the best known tool to achieve this with the required accuracy, which can range from ms to ns depending on the applications and their dynamics. For example:

- In smart grids thousands of interdependent events impact the network every second, and electricity must be routed correctly to microsecond accuracy.
- Autonomous vehicle communications (whether on land, sea, or in the air) for cooperative sensing and positioning applications require very demanding time and synchronisation accuracy (down to ns level)[1].

GNSS is the primary positioning sensor for many automated navigation tasks

Automation has been used to perform navigation tasks for many years, and the current trend towards 'autonomous navigation' is but the last stage of a long term process; indeed autopilots are widely used in maritime and aviation to follow a specified course, and dynamic positioning systems are common in marine engineering. These systems require position or speed as an input, and GNSS is by far the best position and velocity sensor available in most situations. Naturally as the level of autonomy increases, so do the requirements on the source of PVT information (particularly with respect to integrity, continuity and overall trust in the results), and GNSS is complemented by other means to deliver the requested level of performance.

GNSS calibrates other sensors

When GNSS does not meet navigation requirements alone, it works symbiotically with other sensors. For example, visual odometry systems are subject to drift over time as their error is biased. As GNSS error is not subject to bias, the combination of the two sensors provides a better solution than either individual sensor can.

1 www.ignss2018.unsw.edu.au/sites/ignss2018/files/u80/Slides/D3-S2-ThA-Hasan.pdf

The interface of GNSS and automation is not one-way. Automation techniques offer the potential to improve GNSS receiver performance. The use of techniques in real time in-receiver, rather than in post processing, is on the increase.

Automation enhances GNSS navigation performance

Algorithms can augment GNSS by adapting navigation plans to mitigate environmental factors such as multipath, or by utilising historical data to exploit the relationship between environmental factors and measurements. Such techniques are likely to offer significant performance benefits and, as is true of all automation, will present new challenges in testing and assuring safety.

One novel approach addresses multipath for the application of drone delivery by focusing on flight path planning to avoid multipath, rather than eliminating multipath errors in the navigation solution. A 3D model of buildings, combined with GNSS orbital data, is used to predict the occurrence of multipath. A routing algorithm can then be used to plan the optimal route to be followed by the drones, considering both the multipath and obstacles.

Another example uses historical data to relate ionospheric phase scintillation to its effects in the frequency domain. Such an approach allows autonomous detection and response to phase scintillation. Although still in the research and development phase, this provides an excellent example of the benefits that can be delivered through applying new processing techniques to the rapidly increasing volume of data available.

FUSION OF MANY DIFFERENT DATA ENABLES AUTOMATION TO FULFIL ITS REQUIREMENTS

The performance required by advanced automation applications can only be achieved through the integration of many sources of information, combining GNSS, INS, computer vision, and external data such as mapping layers. As an illustration, in level 5 autonomous cars a system will create its own model of reality with data from many different sensors, heavily augmented with external information. Ensuring this data is correctly combined into a coherent solution is the challenge, which must be met across the technology layers; from sensors and networks, to application programming and any human-machine interfaces. Specification, implementation, verification and validation of these layers will need to be rigorous to deliver safe systems.

Fusion of data from the same sources, collected across a network improves robustness through data cross-checking

In applications such as smart grids, synchronisation is crucial. Such networks typically utilise GNSS for timing and synchronisation, but any signal disruption could pose a threat to their stability. Fortunately, as sensors are organised in a network, there is sufficient redundant data available to validate individual measurements, and to perform autonomous monitoring for anomalous events. Furthermore, appropriate action (e.g. re-routing) can be performed if a malfunction is detected at one node. In co-operative intelligent transport systems (C-ITS) the situation is further improved, as receivers are likely to be more diverse, and thus subject to fewer systematic issues such as firmware vulnerabilities. C-ITS requires vehicles to communicate not only between themselves but also with fixed infrastructure. The exchanged information will help establish situational awareness between vehicles communicating about conditions and hazards ahead and allowing independent cross-checking of data.

Hybrid positioning and navigation

To provide precise, reliable and secure localisation in autonomous vehicle applications, multiple navigation technologies must be integrated. Especially in harsh environments, it can be a challenge to ensure correct functioning of safety-critical functions such as collision avoidance systems. For cases where mere dead reckoning is not suitable, more novel approaches are in development including coupling of GNSS, radar, camera, INS and signals of opportunity. Fusion of augmented GNSS and dead reckoning can provide sufficient accuracy for lane level navigation; ultra-tight coupling not only enhances position solutions, but also enables more rapid re-convergence of GNSS.

Adding computer vision data to enhance GNSS-INS hybrid solutions

GNSS and INS are the two most commonly used techniques for navigation, but both have limitations. GNSS is dependent on the signals it receives (loss of signal is not unusual in harsh environments) and INS increases its error rapidly over time. Whilst high-end INS systems can maintain suitable accuracy for many applications (and indeed very high-end systems are used to provide truth data in certain test environments), they are simply too expensive for the mass market, which uses automotive or consumer grade MEMS based INS delivering much lower performance. This low accuracy can however be mitigated by integration with fast image processing and computer vision: image misalignment analysis can be used to address some of the limitations in low cost MEMS sensors and potentially enable more advanced applications.

THALES

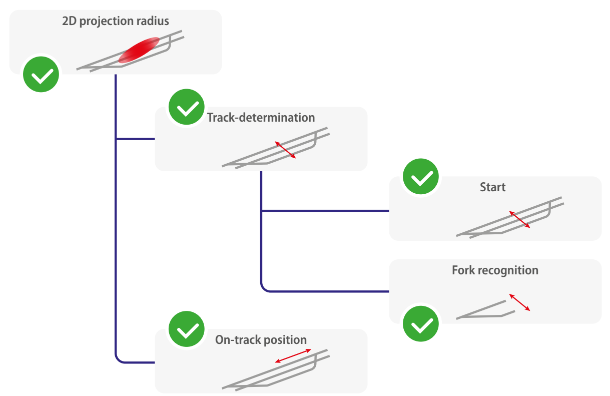
Sensor fusion proof of concept for autonomous train localisation using dual chain architecture with an EGNOS aviation receiver and a Galileo road receiver

It is highly probable that due to harsh environments, GNSS alone could not reach the performances requested for the most critical train localisation applications. To overcome GNSS limitations, Thales, FDC and GeoSat decided to leverage on their aviation and road experience and develop and test a proof of concept of enhanced GNSS systems dedicated to autonomous train localisation.

A proper combination of these two chains, one coming from an "aircraft-based solution" and a second one coming from an "automotive-compliant system", together with the use of a railway track database characterising the GNSS environment at key measuring points (in order to prevent masking or interference situations) has been simulated for the first time in a laboratory. This was carried out using real Signals-in-Space recorded on railway tracks in France, and then fully tested on German regional lines.

The solution proved to be very promising, with meaningful results in terms of both accuracy and integrity monitoring that will be further consolidated in a subsequent activity.

Testimonial provided by the company



AI AND AUTOMATION ARE NOT THE SAME PHENOMENON

Artificial Intelligence (AI) and automation are often seen as the same thing, but in fact they are different. Automation is used to undertake relatively simple tasks which humans would normally have to perform, whereas true AI is empowered to make decisions, which implies the possibility of influencing safety.

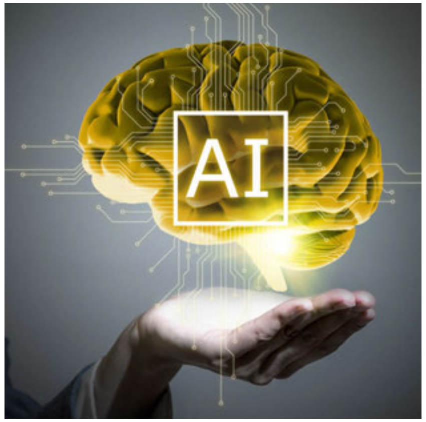
Who is in charge?

Automation is present in one form or another within most industries today. It typically increases productivity by giving the machine monotonous and repetitive tasks, which can be performed with suitably controlled variance. In this context automation is slave to human instruction, whether predetermined or via active control. Typically this is based on bespoke algorithms, which are designed for the specific application only. True AI is different; the machine can make its own decisions. AI is not designed and given a set of instructions to follow. Instead it is given training data, from which it seeks patterns and self-selects the appropriate method. This allows AI to generate emergent strategies to solve problems, which humans either have not, or could not invent. Examples exist firstly in games (computer or board), where the environment and rules are finite and explicitly known. It is not uncommon for humans to adopt game strategies first invented by AIs. From this perspective, many future automation applications may in fact be slave to AI instruction, rather than human.

The paradox of complexity in mundane tasks

Moravec's paradox states "it is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility". As a result, AI is more likely to be adopted in legal practice than in typical GNSS applications. Nevertheless, examples of AI are under development in the transport domain. Whilst a modern autopilot will return control of an aircraft to the human pilot when it falls outside of known parameters, future autopilots are likely to assist human pilots in dealing with failures or unexpected situations – moving away from so-called 'brittle automation'. This will not be an overnight transformation, but instead a stepwise introduction of new capabilities. The first stage of such technology is already deployed in the US military's Auto-Ground Collision Avoidance System (Auto-GCAS) which has recovered control of aircraft when pilots have lost consciousness. AI will also be very important in the future automotive environment (see next page). In both these examples, although GNSS will be a key provider of information, it will also be one source amongst many that the AI utilises to understand its situation and respond accordingly.

AI, automation and GNSS



© Gettyimages

AI and automation interact with GNSS differently, although in both cases GNSS is used as a sensor for the system to help establish PVT knowledge.

- GNSS' role in automation, as discussed in previous pages, is primarily that of a PVT sensor supplying instantaneous input for the system's control loops.
- AI also uses GNSS as an input, in this case to support high level decision making. Typically this requires a large dataset to train from through deep learning. This means AI seeks GNSS data as metadata for their primary dataset, rather than as an instantaneous measurement.

THE FUTURE OF ROAD TRANSPORT FORESEES NO HUMAN INTERVENTION

One area that is blurring the line between AI and automation is self-driving vehicles. Manufacturers are currently working on Level 4 (high) and Level 5 (complete) automation of vehicles. Level 4 automated vehicles will be capable of steering, braking, accelerating, monitoring the vehicle, the roadway and broader environment under "standard" and safe road conditions. Level 5 means no human attention is required at all; indeed, such a vehicle would not even have controls for a human to operate like today.

Human out of the control loop

Levels of automation (0 to 5) are guidelines that describe different levels of autonomy in cars, from a single automated aspect to fully autonomous cars. Level 4 is characterised by hands-off driving which is likely to take place in the early to middle part of the next decade. Level 4 autonomy is not expected to be available in all situations but in carefully defined areas and/or situations – so called "operational design domains". A driver is not required in this stage of automation, but tools like HD mapping, more timely data, car-to-car communication and off-site call centres will be used to deal with unusual hazards. Full Level 5 automation will allow the car to handle all on-road situations, everywhere, and with no operational design domain limitations. This will be enabled by high frequency data updates, a high volume of data available for exchange, and advanced computers processing it. The advent of these cars is expected not long after Level 4, potentially around 2030.

From automation to autonomy

A number of technologies being developed today are bringing automation to vehicles. These include cooperative intelligent transport systems (C-ITS) utilising Vehicle to Vehicle (V2V) and Vehicle to everything (V2X) communication technologies. The current standard of choice for V2V communication is Dedicated Short Range Communication (DSRC), which is based on IEEE 802.11p. Vehicles using this technology can transmit and receive information on speed, position, and performance approximately 10 times per second. Such information can be used by both the driver and/or automated driver assistance systems. V2X communication extends V2V to elements of infrastructure, supplying information on road conditions or hazards. GNSS will play a key role in delivering accurate position and speed data, as well as the necessary precise timestamping of all V2V information. Cybersecurity will be key to ensuring the safety of the application; the exchanged information will have to be authenticated and secure, highlighting the importance of using constellations that offer these services, such as Galileo. Achieving full autonomy will be much more challenging as the ground environment is very unpredictable. It will require approaches such as SLAM (Simultaneous Localisation and Mapping), which enables vehicles to establish details of the environment they are in and determine their location in relation to environmental features. To achieve this, GNSS position information is combined with data from Lidar, radar, ultrasound or cameras. Using processing techniques such as Bayesian estimation, Kalman filtering and/or common-position-shift methods, and object recognition by neural networks, the environment map is updated with the locations of the detected objects, and this information is used to establish the optimal trajectory.

© Qualcomm

AUTOMATION SPREADS TO ALL TRANSPORT MODES

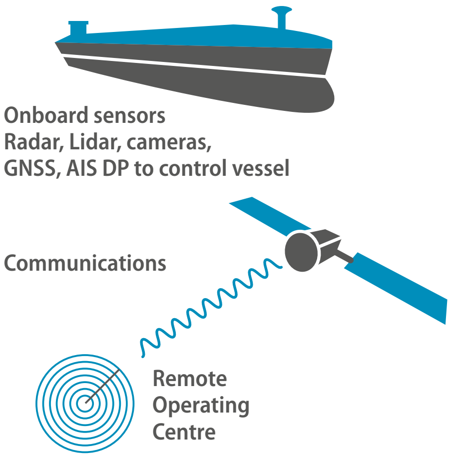
A voyage towards smart shipping

Automation in the maritime industry is commonly used today for domains such as control of machinery, bilge and ballast, energy and power management, heating, ventilation and air conditioning, and many others. In PNT-related applications, its main current uses are found in ports, and in autopilot and dynamic positioning systems on vessels.

Unmanned remotely operated or autonomous surface and sub-surface vessels are becoming more popular for applications such as hydrographic survey, search and rescue[1] and offshore resource exploration. For example, fleets of small-scale autonomous vehicles are routinely used by the UK's National Oceanography Centre, operating together to collect a range of environmental data[2]. Key to this is precise and autonomous navigation. Solutions will undoubtedly incorporate significant sensor fusion, as well as GNSS augmented through PPP, but novel techniques such as horizon detection will also play a role.

GNSS is at the heart of integrated navigation systems

Mariners have always considered not entrusting their safety to any single source of information (position or otherwise) to be good seamanship. This is reflected and formalised in the e-Navigation concept, which is applicable to all kinds of vessels (manned or not) and which is becoming increasingly important as we move towards fully autonomous vessels.



As is the case for any transport mode, autonomous operation requires a high accuracy and integrity level of the positioning system, which must deliver assured PNT.

This is achieved through the combined use of multiple constellation, multiple frequency (augmented) GNSS, and of independent, redundant position, speed and orientation sensors, fully in line with the IMO Performance standards for multi-system shipborne navigation receivers, and with the e-Navigation concept. With the increased level of automation, new sensors appear (Lidar, cameras) that were not commonplace on manned vessels.

1 www.economist.com/science-and-technology/2018/01/02/a-fantastical-ship-has-set-out-to-seek-malaysian-airlines-flight-370
2 Global Marine Technology Trends 2030 Autonomous Systems, Lloyd's Register Group Ltd, QinetiQ and University of Southampton, 2017

Kongsberg testimonial

KONGSBERG

In autumn 2016 the test site Trondheimsfjorden in Norway was inaugurated as the world's first test area officially dedicated to the development of technology for autonomous ships. The test bed is a vital facility for the development of sensors, software and systems that enable autonomous vessels.

Autonomous technology is likely to enable fully or partly unmanned ships to be an important part of the future transport system in Europe and the world. A key element in this domain is the need for reliable GNSS infrastructure for availability, safety and security. Autonomous operations will need to navigate safely in close proximity to other stationary or moving vessels and objects. Galileo will play a vital role in ensuring the service is more resistant to jamming and spoofing. Autonomous operations will require higher redundancy in the instrumentation of the vessel, and high accuracy for situational awareness and accurate proximity zones in e.g. auto-docking (auto-mooring) operations. Autonomous vehicles will also have several other sensors that merge information (sensor fusion) to create proximity zones for the vessel as well as neighbouring objects with high precision and high integrity; the utilisation and availability of Galileo and EGNOS is therefore vital.

Testimonial provided by the company

© Kongsberg

MARITIME AUTONOMOUS SURFACE SHIPS (MASS) ON THE HORIZON

As in other transport or industrial domains, the maritime industry is undergoing a digital revolution enabled, amongst other technologies, by the next generation of communications networks that is already delivering broadband connectivity at competitive prices. This contributes to an increasingly automated and autonomous (maritime) world, which will in the next few years move from smart ships, to smart fleets and to smart shipping.

Broadband connectivity provides the means for remote real-time monitoring and control of vessels from shore, which is seen as one of the key values as well as a milestone towards full autonomy. Indeed, major industry stakeholders such as Rolls-Royce, Wärtsilä, Navtor or Kongsberg have already demonstrated technologies for remotely controlling different types of workboats, such as tugs, platform supply vessels or local container ships. Remote control and autonomous technology is likely to be adopted in other vessel types before 2020. This might be a passenger vessel operating between islands, or a coastal cargo ship, or an autonomous surface vessel used to deploy underwater remotely-operated vehicles.

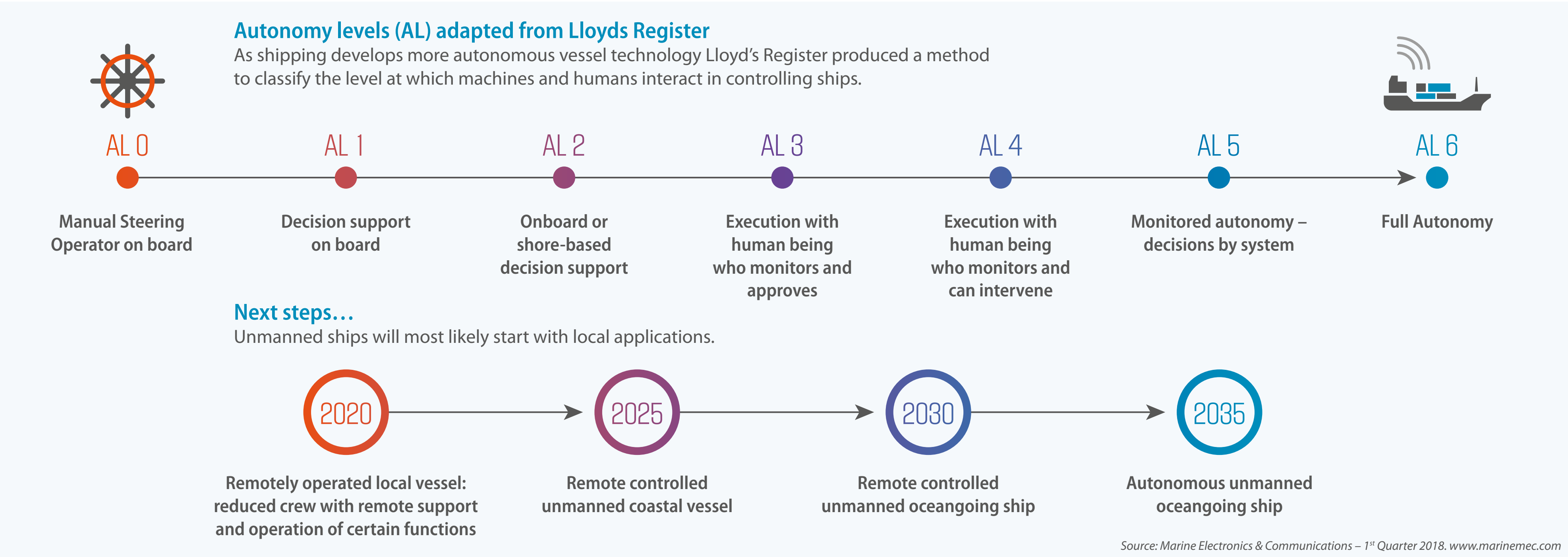
Much in a similar way to the automotive case, autonomous navigation is first arriving through connected vessels, and is progressing stepwise towards full autonomy. Lloyd's Register produced a method to classify the levels at which machines and humans interact in controlling ships, resulting in six "automation levels" (see the graphic below).

Current projects focus on remote control of specific workboats, but there is also significant interest in the area of semi-autonomous ships, plus autonomous or remote control in harbour operations.

For the longer term, some research projects such as the Rolls-Royce-led Machine Executable Collision Regulations for Marine Autonomous Systems (MAXCMAS) project are investigating how autonomous vessels could co-exist with manned ships, and use existing and future satellite capabilities for collision avoidance and communications. MAXCMAS demonstrated that autonomous vessels could comply with the current IMO collision avoidance Colregs regulations*, and in some cases can even exceed the existing requirements for manned ships.

According to industry experts (Rolls-Royce, Lloyd's Register), AL 6 (fully autonomous ocean going vessels) could be operational by 2035, a timeframe not very different from that of the automotive industry.

* Colregs – Convention on the International Regulations for Preventing Collisions at Sea, 1972, amended 2007.



FROM REMOTELY PILOTED DRONES TO AUTONOMOUS FLYING ROBOTS

Professional drone applications already require accurate and reliable tracking, but when advancing to automated applications, with no pilot in line of sight, the need for robust GNSS grows.

Some drone operations are already automated, but end-to-end safety of flight remains the responsibility of a human operator, even in 'beyond line of sight' operations. To deliver the full economic growth and societal benefits expected from drone services, drones must be safely integrated into all classes of airspace through a suitable UTM (Unmanned Traffic Management or UAS Traffic Management) system; the ultimate goal remaining the 'flying taxis' as demonstrated in 2017 in Dubai.

U-space

U-space is Europe's initiative to enable this new service market while ensuring the safe and secure integration of drone operations in urban areas as well as in our countryside. U-space intends to address:

- All operating environments
- All types of airspace
- All kinds of missions
- All categories of drones
- All drone users

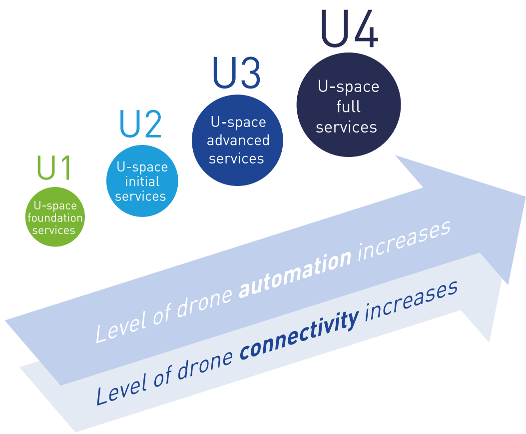
U-space is a set of new services and specific procedures designed to support **safe**, **efficient** and **secure** access to airspace for large numbers of drones, relying on a high level of digitalisation and automation of functions.

Ultimately, U-space will enable complex drone operations with a high degree of automation to take place in all types of operational environments, including urban areas.

The progressive deployment of U-space is linked to the increasing availability of blocks of services and enabling technologies. Over time, U-space services will evolve as the level of automation of the drone increases, and advanced forms of interaction with the environment are enabled.

As is the case in other transport modes, **connectivity** is a key enabler of the planned services and automated functions such as 'Detect and avoid', 'Tactical deconfliction', 'Dynamic geofencing' and 'Collaborative interface with ATC'.

From the GNSS point of view, another key enabler is the assured availability of a PNT system that delivers high accuracy, integrity and robustness. This is likely to be realised by augmented GNSS with dual frequency, SBAS and authentication.



U-space services

U1 (2019+) U-space **foundation services** provide e-registration, e-identification and geofencing.

U2 (2022+) U-space **initial services** support the management of drone operations and may include flight planning, flight approval, tracking, airspace dynamic information, and procedural interfaces with air traffic control.

U3 (2027+) U-space **advanced services** support more complex operations in dense areas and may include capacity management and assistance for conflict detection. Indeed, the availability of automated 'detect and avoid' (DAA) functionalities, in addition to more reliable means of communication, will lead to a significant increase of operations in all environments.

U4 (2035+) U-space **full services**, particularly services offering integrated interfaces with manned aviation, support the full operational capability of U-space and will rely on very high level of automation, connectivity and digitalisation for both the drone and the U-space system.

Credit: The U-space blueprint is the work of the SESAR Joint Undertaking (www.sesarju.eu)

AUTOMATION CONTRIBUTES TO SMART MOBILITY

The world is rapidly urbanizing, and increased congestion is pushing the transport systems of many cities to the limits, costing travellers and municipalities valuable time and money. Innovative ideas, including hybrid transport modes are proposed to help solve the smart mobility equation. Proposals include adding the sky as a third dimension to the urban transport networks, or utilising swarms of self-driving pods. Whatever the transport systems of the future are going to look like, they undoubtedly will be highly automated and in most cases unmanned. Below are some examples of such projects, as well as places where this future is being tested in real conditions.

Airbus Pop.Up / © Italdesign

Pop.Up

Pop.Up is a concept vehicle system designed to relieve traffic congestion in crowded megacities. Pop.Up envisages a modular system for multi-modal transportation that makes full use of both ground and airspace.

The Pop.Up electric and driverless vehicle is shaped as a passenger capsule designed to be coupled with two different and independent electrically propelled modules, the ground module and the air module.

The Pop.Up vehicle combines the flexibility of a small two seater ground vehicle with the freedom and speed of a vertical take-off and landing (VTOL) air vehicle, thus bridging the automotive and aerospace domains.

Pop.Up is an Airbus, Audi and Italdesign project.

Ten cities with autonomous vehicles in use

More than 100 robotic shuttles are on the road worldwide, although not all on a regular road. Many only run students through campus, or deliver goods within factories. Below are ten selected places where actual driverless vehicles are in use today:

1. **Bad Birnbach** (Germany) - 700 metres in regular traffic, from the station to the spa.
2. **Paris** (France) - Three road sections of almost one kilometre along the Île-de-France.
3. **Las Vegas** (USA) - Circuit on Las Vegas Boulevard. Total length just under a kilometre.
4. **Sion** (Switzerland) - Two tracks with a total length of 3.5 kilometres through the entire Old Town.
5. **Hong Kong** (China) - 300-metre track in the West Kowloon Cultural District.
6. **Berlin** (Germany) - Test operation on the Euref campus in Schöneberg. Transportation of employees to the office building.
7. **Nanyang** (Singapore) - 500-metre circuit on the grounds of Nanyang Technological University.
8. **Christchurch** (New Zealand) - One kilometre test track at Christchurch Airport.
9. **Lyon** (France) - Two autonomous shuttles operate a 1.3 kilometre itinerary on the banks of the river Saone.
10. **Sydney** (Australia) - Autonomous shuttle in the city's Olympic Park. Total length of the line is 700 metres.

© 2017 NEXT Future Transportation inc.

Self-driving pods

The Roads and Transport Authority (RTA) of Dubai is testing innovative self-driving pods.

These consist in swarms of autonomous “pods” that can link together, and detach in 5 seconds depending on the destination of riders. Not only do they provide users with on-demand door-to-door transportation, they are also designed to offer services in-motion; during the trip one can call for service modules (bar, shop, toilet, restaurants etc.), which reach and join the passenger’s module, while in motion, without any stops.

The RTA says the autonomous pods would travel on pre-programmed routes in the first few years, but would eventually become accessible for pick up from home using a mobile telephone application.

Dubai’s RTA last year also unveiled plans for a “flying taxi”.

AUTOMATION HAS GREAT POTENTIAL BEYOND TRANSPORT

Integration of autonomous vehicles

For some applications, the integration of autonomous machines offers tangible benefits. For example, in precision agriculture the integration of drones and an autonomous tractor reduces the potential damage caused by the tractor to the crops. It also expands its sensing and application area, whilst addressing the limitations of drones in terms of flight time and load capacity. One of the innovations in development involves small robot fleets operating in swarms. This is the starting point of the coordination and multitasking of multi-robot systems, which consist of large numbers of mostly simple physical robots. Rendezvous of the various vehicles will require very precise coordination, which demands high accuracy, integrity and robustness.

As applications may benefit from both vehicles moving simultaneously, any delay or uncorrelated errors in positioning would be highly detrimental. To address these issues, approaches typically involve the ground vehicle following route planning on GIS through GNSS, or a communications link between the vehicles. When the air vehicle needs to return to the ground vehicle, GNSS allows it to reach the approximate location, and computer vision is utilised to steer the control loops typically through a simple/cheap controller.

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Automation in power grids

Power grids can benefit greatly from automation. Some examples of automation used in these applications include remote fault indicators, smart relays, automated feeder switches, automated capacitors, automated voltage regulators, transformer monitors and automated feeder monitors.

With increasing requirements on existing infrastructure, GNSS can be used to obtain microsecond-level timing information, synchronous sampling and time stamping of data. These applications are critical to ensuring that grid relays can send power without causing any tripping. Such technologies have, for instance, enabled the 100 MW battery installation delivered by Tesla in Australia.

GNSS is therefore of interest for high performance synchronisation of power grid networks, especially the provision of time services to meet the needs of high accuracy in-time determination and event synchronisation, and the use of authenticated and certified time.

Automation in agriculture

With the exponential growth of the Earth's population, agriculture/food production needs to make another step into automation. The current needs are crop protection and crop production. Autonomous vehicles are now widely used in the large-scale farming industry. Advanced Farming System (AFS) hardware delivers guidance correction to an acceptable level of accuracy and provides data such as machine location, diagnostics, and fuel and engine status.

Drones are a new, high-precision way to obtain geo-tagged images from the air and 3D inspection models with 1 mm resolution. New MEMS sensors (accelerometers, gyros, magnetometers, and often pressure sensors), smaller GNSS receivers, incredibly powerful processors, and a range of digital radios make drones a perfect automatic/autonomous worker.

Automated seabed surveying

70% of the Earth is covered by water, but so far just 20% of it has been surveyed (Mars, Venus and the Moon are better surveyed). This was highlighted when searchers trying to locate the missing flight MH370 discovered two underwater volcanoes, one bigger than Mount Vesuvius. Recognising the need for faster advancement in seabed mapping, GEBCO (General Bathymetric Chart of the Oceans) and the Nippon Foundation launched project Seabed 2030 with the aim of facilitating the complete mapping of the global ocean floor by the year 2030. In parallel, the Shell Ocean Discovery XPRIZE was launched. This is a three year global competition challenging teams to advance ocean technologies for rapid, unmanned and high-resolution ocean exploration[1]. Proposed innovative approaches include artificial intelligence, aerial drones, underwater robotic swarms, lasers, and autonomous surface and underwater vehicles; high-accuracy GNSS is used for all but sub-surface positioning.

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1 oceandiscovery.xprize.org

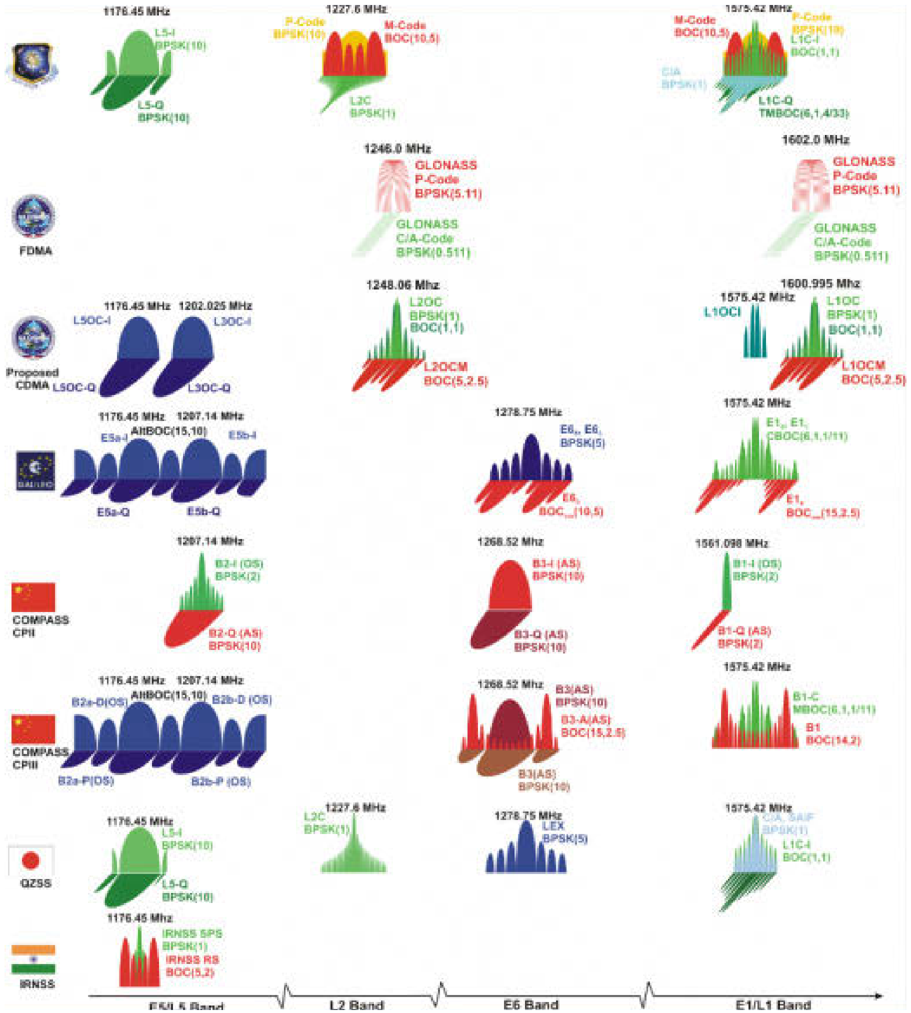
ANNEXES

ANNEX 1: GNSS CONSTELLATIONS AND FREQUENCIES

GNSS CONSTELLATIONS

Parameter	GPS	GLONASS	Galileo	BeiDou
Orbital Period	11hrs 58min	11hrs 15mins	14hrs 04mins	12hrs 37min
Orbital Height	22,200 Km	19,100 Km	23,222 Km	21,150 Km
Inclination	55°	64,8°	56°	55°
Number of Orbital Planes	6	3	3	6
Number of satellites	24 operational + 6 spares	21 operational + 3 spares	24 operational + 6 spares	27 MEOs + 5 GEOs + 3 IGSOs
Reference frame	WGS-84	PZ90	GTRF	CGCS 2000
Reference time	GPS Time (GPST)	GLONASS Time (GLONASST)	Galileo System Time (GST)	BeiDou Time (BDT)

GNSS FREQUENCIES



Source: Navipedia http://www.navipedia.net/index.php/GNSS_signal

ANNEX 2: AUGMENTATION SYSTEMS

Augmentation systems improve GNSS key performance parameters; in particular accuracy, integrity and availability. To meet high-accuracy demands prior to the availability of satellite-based augmentation or high-precision PPP solutions, there has been a proliferation of public and private providers of ground based RTK and DGNSS solutions. Thus, for those users requiring high GNSS performance (e.g. geodetic survey, maritime port operations), there is already a wide choice of potential solutions with most states having two or three providers to choose from at a national level. Between them, these providers have hundreds of ground monitoring stations and transmitters.

Globally, options exist from the availability of satellite-based networks, or commercial providers operating global level RTK, DGNSS or increasingly, PPP networks.

The main commercial options at a global level are summarised in the table on the right.

Public augmentation systems

Satellite-based augmentation systems utilise a regional network of ground monitoring stations with known position, and transmit correction information messages from dedicated satellites, to enable end users to apply corrections from individual GNSS satellites.

Name	Stated accuracy	Supported Constellations	Owned by
BDSBAS	Horizontal: <5m Vertical: <8m	Current: BDS + GPS + GLONASS Future: BDS + GPS + GLONASS + Galileo	China
EGNOS	Horizontal: <1m Vertical: <2m	Current: GPS Future: GPS + Galileo (FOC in 2020)	Europe
GAGAN	Horizontal: 1.5m Vertical: 2.5m	GPS	India
MSAS	<2 m	GPS	Japan
QZSS-SBAS	0.01-1m	Current: GPS Future: GPS + GLONASS + Galileo (FOC in 2020)	Japan
SDCM	Horizontal: 0.5m Vertical 0.8m	Current: GPS + GLONASS Future: BDS + Galileo + QZSS	Russia
WAAS	Horizontal: <1m Vertical: <1.5m	GPS	USA
KASS	~3m		Korea

Ground-based augmentation systems utilise a network of national or regional ground reference stations, from which radio transmitters send measurements concerning GNSS corrections (provided by accurately surveyed ground stations) directly to end users.

While **SBAS** and **GBAS** above are primarily developed for civil aviation needs, the **IALA DGNSS** system based on a network of maritime radio beacons used as reference stations and transmitters, has also been operational for over 20 years serving the maritime community.

Name	Service	Stated performance	Supported Constellations	Method	Owned by
Omnistar	VBS	<1m	GPS	DGNSS	Trimble
	HP	10cm	GPS	LR-RTK	
	XP	15cm	GPS	PPP	
	G2	<10cm	GPS + GLONASS	PPP	
RTX	ViewPoint	<1m	GPS + GLONASS + BeiDou + Galileo + QZSS	PPP	Trimble
	RangePoint	<50cm	GPS + GLONASS + BeiDou + Galileo + QZSS	PPP	
	FieldPoint	<20cm	GPS + GLONASS + BeiDou + Galileo + QZSS	PPP	
	CenterPoint	<4cm	GPS + GLONASS + BeiDou + Galileo + QZSS	PPP	
	VRS Now	<2cm	GPS + GLONASS + BeiDou + Galileo + QZSS	PPP	
Starfix/ Seastar	XP	10cm	GPS	PPP	Fugro
	G2	10cm	GPS + GLONASS	PPP	
	G2+	3cm	GPS + GLONASS	PPP	
	G4	5-10cm	GPS + GLONASS + BeiDou + Galileo	PPP	
	L1	1.5m	GPS	DGNSS	
	SGG	<1m	GPS + GLONASS	DGNSS	
	XP2	10cm	GPS + GLONASS	PPP	
Atlas	Basic/H100	50cm	GPS + GLONASS + BeiDou + Galileo[1]	PPP	Hemisphere
	H30	30cm	GPS + GLONASS + BeiDou + Galileo[1]	PPP	
	H10	8cm	GPS + GLONASS + BeiDou + Galileo[1]	PPP	
Starfire	SF2	5cm	GPS + GLONASS	PPP	John Deere
C-Nav	C1	5cm	GPS	PPP	Oceaneering International
	C2	5cm	GPS + GLONASS	PPP	
Veripos	Apex	10-20cm	GPS	PPP	Hexagon AB
	Apex^2	5cm	GPS + GLONASS	PPP	
	Apex^5	<5cm	GPS + GLONASS + BeiDou + Galileo + QZSS		
	Ultra	15cm	GPS	PPP	
	Ultra^2	8cm	GPS + GLONASS	PPP	
	Standard	1m	GPS	DGNSS	
	Standard^2	1m	GPS + GLONASS	DGNSS	
TerraStar	TerraStar D	10cm	GPS + GLONASS	PPP	Hexagon AB
	TerraStar L	40cm	GPS + GLONASS	PPP	
	TerraStar M	1m	GPS + GLONASS	DGNSS	
	TerraStar C	2-3cm	GPS + GLONASS	PPP	

1 Planned for future versions

ANNEX 3: GNSS KEY PERFORMANCE PARAMETERS

© Gettyimages

Availability: is the percentage of percentage of time the positioning or timing solution can be computed by a user in the coverage area.

- **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.

Accuracy: is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion –usually 95%- of samples would fall if measured.

This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre-level: 1-10 metres.

Continuity: is the ability of a system to perform its function (deliver PNT services with the required performance levels) without 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.

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.

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.

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

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.
- **Hot start:** the receiver understands the current situation – typically taking a few seconds.

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

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: LIST OF ACRONYMS

3D	Three Dimensional
AAL	Augmented Approaches to Land
ADAS	Advanced Driver Assistance System
ADC	Analogue-to-digital converter
ADS-B	Automatic Dependent Surveillance-Broadcast
AFS	Advanced Farming Systems
AGC	Automatic Gain Control
A-GNSS	Assisted GNSS
AHWG	Ad Hoc Working Group
AI	Artificial Intelligence
AIS	Automatic Identification System
AltBOC	Alternative BOC modulation
AM	Amplitude Modulation
AoA	Angle of Arrival
ARAIM	Advanced RAIM
AR	Augmented Reality
ARNS	Aeronautical Radio Navigation Service
ASAS	Airborne Separation Assistance System
Auto-GCAS	Automatic Ground Collision Avoidance System
BDS	BeiDou Navigation Satellite System
BeiDou	Chinese GNSS, formerly known as Compass
BOC	Binary Offset Carrier modulation
BVLOS	Beyond Visual Line of Sight
CAT I, II, III	ILS Categories for precision instrument approach and landing
CDMA	Code Division Multiple Access
CED	Clock and Ephemeris Data
C-ITS	Cooperative Intelligent Transport System
CLAS	Centimeter Level Augmentation Service (QZSS)
CLOE	Connecting and Locating Objects Everywhere
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
CS	(Galileo) Commercial Service
CSAC	Chip Scale Atomic Clock
CW	Continuous Wave
DGNSS	Differential Global Navigation Satellite System
DME	Distance Measuring Equipment
DSRC	Dedicated Short Range Communication
DoA	Direction of Arrival
EC	European Commission
EU28	European Union (28 Member States)
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
E-GNSS	European GNSS
EKF	Extended Kalman Filter
eLORAN	enhanced Long-range Navigation
ELT	Emergency Locator Transmitter
EO	Earth Observation
EPIRB	Emergency Positioning Indicator Radio Beacon
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ES	Enhanced Services
EU	European Union
EVS	Enhanced Vision Systems
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
FOC	Full Operational Capabilities
FPV	First Person View
GADSS	Global Aeronautical Distress and Safety System
GAGAN	GPS Aided Geo Augmented Navigation
GA	General Aviation
GBAS	Ground Based Augmentation System
GCP	Ground Control Points
GEO	Geostationary Orbit
GIS	Geographic Information System
GLONASS	Russian GLObalnaya NAvigatsionnaya Sputnikovaya Sistema
GMRS	General Mobile Radio Service
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European GNSS Agency
GSO	Geosynchronous Orbit
H2020	Horizon 2020
HAD	Highly Automated Driving
HAS	High Accuracy Service (Galileo)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ICAO	International Civil Aviation Organisation
ICG	International Committee on GNSS
IF	Intermediate Frequency
IGSO	Inclined Geosynchronous Orbit
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IOC	Initial Operational Capabilities
IoT	Internet of Things
IR	Integrity Risk
IS	Initial Services
IT	Information Technologies
ITS	Intelligent Transport System
JRC	(EC´s) Joint Research Centre
KASS	Korean Augmentation Satellite System
KPP	Key Performance Parameter
LBS	Location Based Service
LDS	Location Detection System
LEO	Low Earth Orbit
LIDAR	Light Detection And Ranging
LNA	Low-Noise Amplifier
LP	Location Protocol
LPV	Localizer Performance with Vertical guidance
LPWAN	Low Power Wide Area Network
LSQ	Least Squares
LTE	Long-Term Evolution, commonly known as 4G LTE
MASS	Maritime Autonomous Surface Ship
MBES	Multi-Beam Echo Sounder
MCMF	Multiple-Constellation Multiple-Frequency
MC	Multi-Constellation
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
MOPS	Minimum Operational Performance Standards
MR	Mixed Reality
MSAS	MTSAT Satellite Augmentation System
NavIC	NavIC- Indian Regional Navigational Satellite System
NLOS	Non Line Of Sight
NMA	Navigation Message Authentication
NMEA	National Marine Electronics Association
OBD	On-Board Diagnosis
OBU	On-Board Unit
OCX	Next Generation Operational Control Segment (GPS)
ONU	On-board Navigation Unit
OS	(Galileo) Open Service
OS-NMA	Open Service Navigation Message Authentication
OSR	Observation Space Representation
PAAS	Positioning As A Service
PBN	Performance Based Navigation
PLB	Personal Locator Beacon
PLLs	Phased Locked Loops
PND	Portable Navigation Device
PNT	Positioning, Navigation and Timing
PPP	Precise Point Positioning
PVT	Position, Velocity, Timing
QZSS	Quasi-Zenith Satellite System
R&D	Research and Development
RAIM	Receiver Autonomous Integrity Monitoring
RFID	Radio-Frequency Identification
RF	Radio-Frequency
RLS	Return Link Service
RNP	Required Navigation Performance
RNSS	Regional Navigation Satellite System
RPAS	Remotely Piloted Aircraft System
RSSI	Received Signal Strength Indication
RTCA	Radio Technical Commission of Aeronautics
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SAR	Search and Rescue
SAS	Signal Authentication Service
SAW	Surface Acoustic Wave
SBAS	Satellite Based Augmentation System
SDCM	System for Differential Corrections and Monitoring
SDG	Sustainable Development Goal
SF/DF/TF	Single/Dual/Triple Frequency
SiP	System in Package
SIS ICD	Signal in Space Interface Control Document
SIS	Signal in Space
SLAM	Simultaneous Location And Mapping
SLAS	Sub-meter Level Augmentation Service (QZSS)
SNAS	Satellite Navigation Augmentation System
SoC	System on Chip
SoL	Safety of Life
SOOP/SoOp	Signal of Opportunity
SPP	Single Point Position
SVS	Synthetic Vision Systems
SW	Software
T&S	Timing and Synchronisation
TATT	The Telecommunications Authority of Trinidad & Tobago
TDoA	Time Difference of Arrival
ToF	Time of Flight
TTFF	Time To First Fix
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UHF	Ultra-High Frequency
UNIFE	Union des Industries Ferroviaires Européennes (Association of the European Rail Industry)
UNISIG	Union Industry of Signalling (Industry consortium developing the ERTMS technical specifications)
UNOOSA	United Nations Office for Outer Space Affairs
UTC	Coordinated Universal Time
UTM	UAS Traffic Management Systems
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
VBS or VRS	Virtual Base Station or Virtual Reference Station
VDES	VHF Data Exchange System
VFR	Visual Flight Rules
VGA	Video Graphics Array
VOR	VHF Omnidirectional Radio Range
VTOL	Vertical Take-off and Landing
WAAS	Wide Area Augmentation System
Wi-Fi	Wireless Fidelity. Wireless communication protocols standardised by IEEE 802.11 (ISO/CEI 8802-11)
WLSQ	Weighted Least Squares

ANNEX 5: METHODOLOGY USED FOR CREATING THE GNSS USER TECHNOLOGY REPORT

This GNSS User Technology Report uses the GSA's internal Technology Monitoring Process (TMP).

It complements the market monitoring and forecasting process, and its objective is to monitor trends and developments in the GNSS supply industry. It supports the GSA in: defining the best strategy towards Galileo market adoption; provision of updated statistics on Galileo penetration in user terminals and chipsets; and analysing Galileo 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, 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: Avidyne, Broadcom, CSR, Esterline, Furuno, Garmin, Hemisphere GNSS, Honeywell, Infineon, Intel, Japan Radio Co., John Deere, Kongsberg, Leica Geosystems AG, Mediatek, NavCom Technology, Nottingham Scientific Ltd, NovAtel, Omnicom, Orolia, Qualcomm, Rockwell Collins, Septentrio, SkyTraq Technology, STMicroelectronics, Texas Instruments, Thales Avionics, Topcon, Trimble, u-blox, and Universal Aviation.

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.

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 infrastructure;
- Managing the provision of quality services that ensure user satisfaction in the most cost-efficient manner;
- Engaging market stakeholders to develop innovative and effective applications, value-added services and user technology that promote the achievement of full European GNSS adoption;
- Ensuring that European GNSS services and operations are thoroughly secure, safe and accessible.

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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 EGNOS in aviation, agriculture, LBS, maritime, road, rail, surveying and timing & synchronisation; preparing the market for the uptake of Galileo in all 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 238 demonstrations of E-GNSS applications; 79 products, 192 prototypes, 23 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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