EARTH OBSERVATION AND GLOBAL NAVIGATION SATELLITE SYSTEMS

ANALITICAL REPORT PART I (AVIATION AND SPACE)

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ABSTRACT

The EU Space Programme is a business growth enabler that stimulates the economy and pushes the bar of innovation. The EUSPA EO & GNSS Market Report is the ultimate guide to anyone who seeks to make the EU Satellite Navigation and Earth Observation technologies part of their business plan and develop new space downstream applications. More than ever society relies on innovative solutions to deal with the big data paradigm. Earth Observation (EO) and Global Navigation Satellite System (GNSS) data is becoming increasingly important to these innovative solutions through dozens of applications that are emerging or already in use by citizens, businesses, governments, industry, international organisations, NGOs and researchers around the world. The study provides analytical information on the dynamic GNSS and EO markets, along with in-depth analyses of the latest global trends and developments through illustrated examples and use cases. Using advanced econometric models, it also offers market evolution forecasts of GNSS shipments or EO revenues spanning to 2031. With a focus on Galileo/EGNOS and Copernicus, the report highlights the essential role of space data across 17 market segments including, Agriculture; Aviation and Drones; Biodiversity, Ecosystems and Natural Capital; Climate Services; Consumer Solutions, Tourism, and Health; Emergency Management and Humanitarian Aid; Energy and Raw Materials; Environmental Monitoring; Fisheries and Aquaculture; Forestry; Infrastructure; Insurance and Finance; Maritime and Inland Waterways; Rail; Road and Automotive; Urban Development and Cultural Heritage; and Space. This article represent the brief overview essential role of space data across 2 market segments including, Aviation and Drones and Rail, Road and Automotive.

KEYWORDS: *GNSS, aviation, space,* Low Earth Orbits,

Brief description based on the Copernicus Programme report, which is coordinated and managed by the European Commission and is the European Union's Earth Observation and Monitoring Programme (www.euspa.europa.eu)

I. INTRODUCTION

For the first time for the European Union Agency for the Space Programme (EUSPA), to introduce the first published EUSPA Earth Observation (EO) and Global Navigation Satellite System (GNSS) Market Report.

The European Global Navigation Satellite System (GNSS) allows users with compatible devices to determine their position, velocity and time by processing signals from satellites. It consists of two elements: Galileo; and the European Geostationary Navigation Overlay Service (EGNOS). EGNOS is Europe's regional Satellite-Based Augmentation System (SBAS). It improves the quality of open signals from the US Global Positioning System (GPS) and (soon) Galileo.

The European Association of Remote Sensing Companies (EARSC) is a not-for-profit organisation which coordinates and promotes the activities of European companies engaged in delivering Earth Observation-derived geo-information services. Acting as a bridge between industry, decision makers and users and covering the full EO value chain (from data acquisition through processing, fusion, analysis and final geo-information products and services), the organisation's members span across 25 countries and include over 130 companies (including SMEs and start-ups) [1].

Coordinated and managed by the European Commission, Copernicus is the European Union's Earth Observation (EO) and Monitoring programme. Copernicus relies on its own set of satellites (Sentinels), as well as contributing missions (existing commercial and public satellites), and a variety of technologies and in-situ measurements systems at atmosphere, land and ocean. The accurate and reliable data generated is turned into value-added information by the Copernicus Services for different thematic domains: atmosphere monitoring; marine environment monitoring; land monitoring; climate change monitoring; and security and emergency management.

Most data generated by Copernicus are made available to anyone globally based on a Full, Free and Open (FFO) data policy. They are accessible through various services, including a set of cloud-based platforms called Data and Information Access Services (DIAS).

The objective of the EU GOVernmental SATellite COMmunication (GOVSATCOM) initiative is to ensure the availability of reliable, secure and cost-effective satellite communication services for EU and national public authorities managing emergency and security-critical missions, operations and infrastructures.

2021 has been a year of accomplishments for the European Union in space. The first-ever integrated Space Programme, gathering the two satellite navigation systems, Galileo and EGNOS, the EU Earth Observation system, Copernicus, and GOVSATCOM, the upcoming system for secure governmental communications, is now in place. EUSPA has an extended mandate, including the provision of satellite-based services for Galileo and EGNOS and development of the GOVSATCOM Hub, enhanced security responsibilities, and the market uptake of Galileo, EGNOS, commercial utilization of Copernicus, and the development of GOVSATCOM users' phase, among others.

A strategic goal of the European Commission (EC) space strategy is to reinforce Europe's strategic autonomy in accessing and using space, and this in a secure and safe environment.

Since its inception, the report has established itself as the most authoritative reference document for information on the global GNSS market.

II. GNSS DOWNSTREAM SPACE APPLICATION MARKET

Earth Observation (EO) refers to remote sensing and in-situ technologies used to capture the planet's physical, chemical, and biological systems and to monitor land, water (i.e. seas, rivers, lakes) and the atmosphere. Satellite-based EO by definition relies on the use of satellite-mounted payloads to gather data about Earth's characteristics. As a result, satellite-based platforms are suitable for monitoring and identifying changes and patterns for a range of physical, economic, and environmental applications globally. Once processed, EO data can be assimilated into complex models to produce information and intelligence (e.g. forecasts, behavioural analysis, climate projections, etc.), and complemented by in-situ measurements.

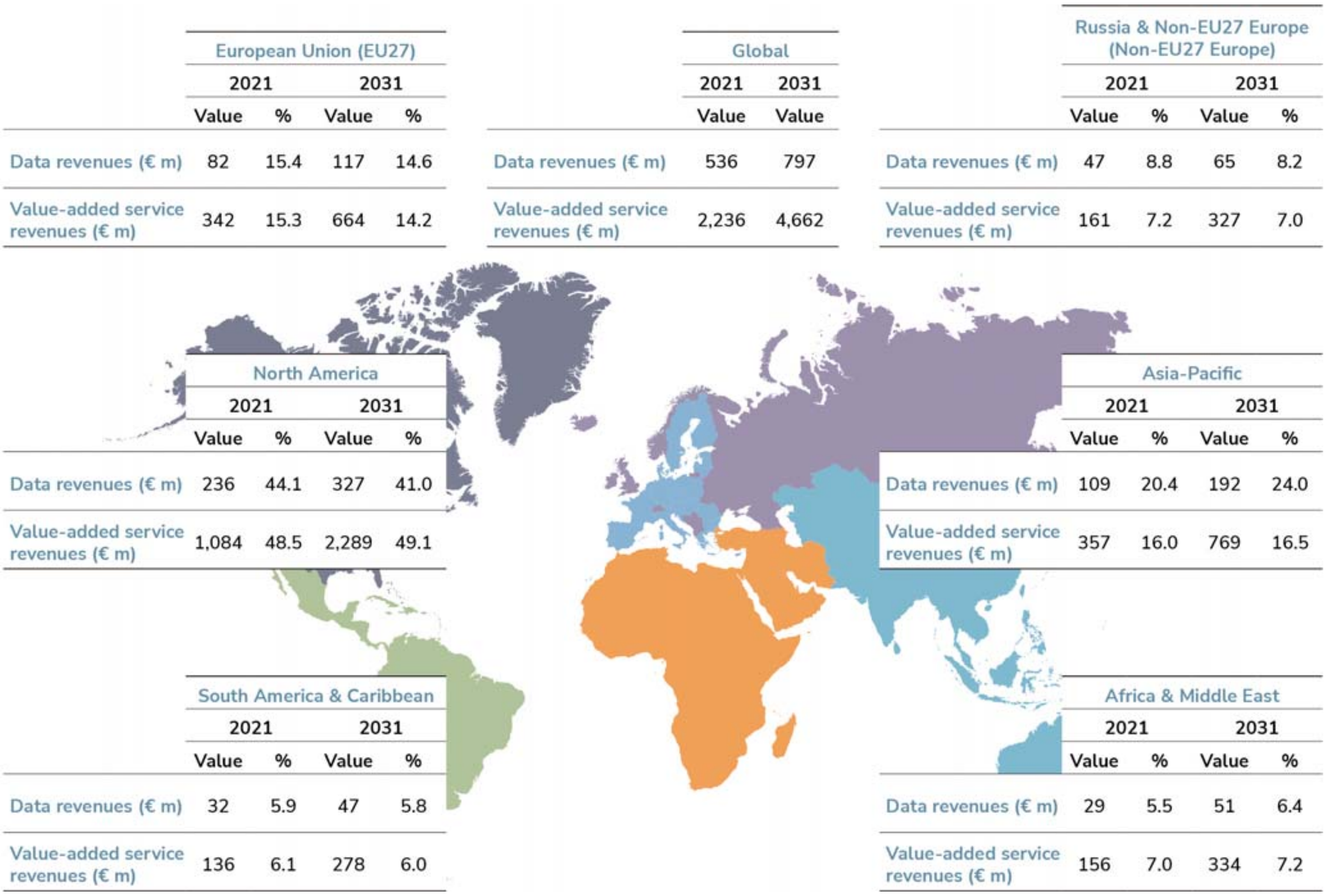
Firstly, different types of sensors utilize different EO technologies:

- *Optical or thermal sensors* are payloads monitoring the energy received from the Earth due to the reflection and re-emission of the Sun's energy by the Earth's surface or atmosphere. They operate between the visible and infrared wavelengths of the electromagnetic spectrum.
- *Radar sensors* are payloads operating in the lower part of the spectrum (longer wavelengths). Most of these sensors send energy to Earth and measure the feedback from the Earth's surface or atmosphere, enabling day and night monitoring during all-weather conditions.

The second essential parameter in EO is the sensor resolution.

- *Spatial resolution* defines the size of the pixels analysed by the sensors. EO satellites can be distributed into three categories based on this parameter: Low and medium resolution, High resolution, and Very-High Resolution.
- *Temporal resolution defines* the frequency at which the data is acquired for a defined area. The needs can vary substantially for this parameter, with applications requiring images every day or every few hours, whilst others require updates only every few weeks.

Spectral resolution is also considered in the case of optical sensors. This is defined by the width of the spectrum bands that can be distinguished by the payload, enabling some applications that require the ability to analyse specific wavelengths.



European Union (EU27)	2021 Value	2021 %	2031 Value	2031 %
Data revenues (€ m)	82	15.4	117	14.6
Value-added service revenues (€ m)	342	15.3	664	14.2

Global	2021 Value	2031 Value
Data revenues (€ m)	536	797
Value-added service revenues (€ m)	2,236	4,662

Russia & Non-EU27 Europe (Non-EU27 Europe)	2021 Value	2021 %	2031 Value	2031 %
Data revenues (€ m)	47	8.8	65	8.2
Value-added service revenues (€ m)	161	7.2	327	7.0

North America	2021 Value	2021 %	2031 Value	2031 %
Data revenues (€ m)	236	44.1	327	41.0
Value-added service revenues (€ m)	1,084	48.5	2,289	49.1

Asia-Pacific	2021 Value	2021 %	2031 Value	2031 %
Data revenues (€ m)	109	20.4	192	24.0
Value-added service revenues (€ m)	357	16.0	769	16.5

South America & Caribbean	2021 Value	2021 %	2031 Value	2031 %
Data revenues (€ m)	32	5.9	47	5.8
Value-added service revenues (€ m)	136	6.1	278	6.0

Africa & Middle East	2021 Value	2021 %	2031 Value	2031 %
Data revenues (€ m)	29	5.5	51	6.4
Value-added service revenues (€ m)	156	7.0	334	7.2

Figure 1. EO demand world map

Copernicus delivers accurate and reliable information in the field of environment and security and supports a wide range of Union policies in domains such as agriculture, environment, energy, health, civil protection, humanitarian aid and transport. Mainly tailored to the needs of public authorities, Copernicus also serves research, academic, commercial and other private users. The system consists of three main components: a space component, which delivers data from a fleet of dedicated observation satellites (the 'Sentinels') and from contributing missions; an in-situ component which collects data acquired by a multitude of sensors at air-, sea- and ground-level; and a service component which transforms the wealth of satellite and in-situ data into timely and actionable information products.

The programme is managed by the European Commission and implemented in partnership with the Member States, European Space Agency (ESA), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Ocean International.

The Sentinels are the Earth Observation satellites dedicated to the Copernicus programme and are designed to meet the needs of the Copernicus services and their users. Made-up of six families, they ensure an independent and autonomous Earth Observation capacity for Europe with global coverage. They deliver observations (including day and night, all-weather observations) which serve a wide range of user needs related to land and ocean surfaces, atmospheric measurements, air quality, emergency situations, and so on.

• Sentinel-1A & -1B provide all-weather, day and night radar imagery for land and ocean services.

Sentinel-3A & -3B provide optical, radar and altimetry data for marine and land services.

• Sentinel-6 provides radar altimetry data to measure global sea-surface height, primarily for operational oceanography and for climate studies.

• Sentinel-2A & -2B provide optical imagery for land and emergency services.

• Sentinel-5P provides atmospheric data, bridging the gap between Environ-mental Satellites (ENVISAT) and future Sentinel-5 data.

• Sentinel-4 and 5 are payloads to be respectively embarked aboard EUMETSAT MTG-S and Metop-SG satellites, in order to provide data for atmospheric composition monitoring (to be launched early 2024).

Radio Navigation Satellite Services (RNSS) is infrastructure that allows users with a compatible device to determine their position, velocity and time by processing signals from satellites. RNSS signals are provided by a variety of satellite positioning systems, including global and regional constellations and Satellite-Based Augmentation Systems:

Global constellations i.e. Global Navigation Satellite System (GNSS): GPS (USA), GLONASS (Russian Federation), Galileo (EU), BeiDou (PRC).

• Regional constellations: QZSS (Japan), NavIC (India), and BeiDou regional component (PRC).

• Satellite-Based Augmentation Systems (SBAS): WAAS (USA), EGNOS (EU), MSAS (Japan), GAGAN India), SDCM (Russian Federation) and SNAS (PRC).

This Market Report considers the GNSS market defined as activities where GNSS-based positioning, navigation and/or timing is a significant enabler of functionality. The GNSS market presented in this report comprises device revenues, revenues derived from augmentation and added-value services, (which together form 'Services') attributable to GNSS.

Augmentation services include software products and content such as digital maps, as well as GNSS augmentation subscriptions. Added-value service revenues include data downloaded through cellular networks specifically to run location-based applications (such as navigation), as well as the GNSS- attributable revenues of smartphone apps (sales revenue, advertisements and in-app purchases), subscription revenues from fleet management services, drone service revenues across a range of industries, and so on. Both services are shown on the World Map (next page) together as 'Services'.

For multi-function devices such as smartphones, the revenues include only the value of GNSS functionality - not the full device price. Therefore, a case-specific correction factor is used:

• GNSS-enabled smartphone: Only the value of GNSS chipsets is counted.

• Aviation: The value of the GNSS receiver inside the Flight Management System is taken into account, in addition to the GNSS-specific revenues driven by the certification process.

• Precision Agriculture system: The retail value of the GNSS receivers, maps, and navigation software is counted.

Search and Rescue devices: For Personal Locator Beacons and Emergency Locator Transmitters, only the price differential between GNSS and non-GNSS devices is included.

Global annual GNSS receiver shipments will grow continuously across the next decade (from 1.8 bn units in 2021 to 2.5 bn units in 2031). The vast majority are associated with the Consumer Solutions, Tourism and Health segment which contributes roughly 92% of all global annual shipments thanks to the enormous numbers of smartphones and wearables being sold on an annual basis. From a regional point of view, it is clear that Asia-Pacific will continue its reign as the largest market.

The overall installed base will grow from 6.5 bn units in 2021 to 10.6 bn units in 2031. Similar to global shipments, the lion's share of the installed base is dominated by the Consumer Solutions segment, accounting for 89% of global GNSS devices in use for 2021 and 86% in 2031. This drop of 3% in global share over the next decade is mainly influenced by the declining share of smartphones across all GNSS devices as there is a global trend towards extending the useful life of a smartphone, which in turn translates into a decrease in smartphone shipments. In parallel, the growing adoption and integration of In-vehicle Systems amongst new car shipments pushes the share of the Road and Automotive segment amongst the global installed base of GNSS devices from 9% in 2021 to 12% in 2031.

Looking at other segments (graphs in the bottom-right), Aviation and Drones is a significant market expected to grow from 42 m units in 2021 to 49 m in 2031. The Maritime segment is the second largest market in 2021, but sees it global share of 17% in 2021 (corresponding to 11 m units) drop to 16% (17 m in 2031), whilst Agriculture becomes the second largest market reaching a share of 18% in 2031 (roughly 20 m units in 2031, up from less than 5 m units in 2021).

The global GNSS downstream market revenues from both devices and services will grow from I99 bn in 2021 to 492 bn in 2031 with a CAGR of 9.2%. This growth is mainly generated through the revenues from added-value services. Combined, services revenues (i.e. both added-value services and augmentation services) will account for 405 bn in 2031, more than 82% of the total Global GNSS downstream market revenues.

Road and Consumer solutions dominate all other market segments in terms of cumulative revenue with a combined total of 90% for the forecasting period 2021-2031.

In the Road sector, most revenues are generated by devices used for navigation (In-Vehicle Systems (IVS)), emergency assistance, ADAS as well as fleet management applications (including insurance telematics), whereas Consumer Solutions revenues mainly come from the data revenues of smartphones and tablets using location-based services and applications.

The adjacent table shows the regional market shares for Components and Receiver manufacturers in 2019 for each market segment. The data are created using themethodology described on the previous page. European companies account for a quarter of the global GNSS Components and Receiver manufacturers market in 2019 (compared to 27%

in 2017). The European industry's market share in this value chain category varies across market segments. While it has above average market shares in segments such as Road (53%), Maritime (47%) and Space (65%), it has below average market shares in segments such as Consumer Solutions (7%), Aviation (17%), Rail (14%), and Drones (10%) (Table 1).

Table 1

Europe's 2019 market share in Components & Receivers, by market segments

	Europe	North America	Asia +Russia		Europe	North America	Asia +Russia
Consumer Solutions	7%	45%	47%	Agriculture	20%	47%	33%
Road and Automotive	53%	25%	22%	Geomatics	35%	31%	33%
Manned Aviation	17%	81%	2%	Emergency Response	33%	39%	13%
Rail	14%	15%	71%	Drones	10%	42%	48%
Maritime	47%	27%	26%	Critical Infrastructures	36%	50%	12%
Space	65%	19%	17%				

Note: Segment share for Rest of the World is not shown in this table.

III. AVIATION AND DRONES

Aviation is one of the main drivers behind increasing global connectivity. In comparison, drones are a relatively recent technology which can put a payload anywhere it is needed. The aviation and drones segment encompasses services and products used by aviation and drone operators and industry. This includes airlines, pilots, helicopter operators, drone operators, airports and air navigation service providers.

Aviation uses GNSS extensively, with Satellite-Based Augmentation Systems (SBAS) providing better access to small and medium airports through Performance Based Navigation procedures, increasing safety and enabling business growth across Europe. GNSS is the primary source of navigation for aviation and drones, and meets the present-day performance requirements for all airspaces, from low-level to sub-space. GNSS supports advances in urban air mobility with evaluation of flight risk (e.g. geofencing, populated area avoidance, landing site optimisation), automation and tracking through position self-reporting (known as Electronic Conspicuity).

Combining GNSS and EO data advances emissions monitoring systems. EO itself enables the monitoring of volcanic ash clouds, emissions, terrain (supporting optimised routing), flight procedure development and flight planning. This benefits airlines, leisure pilots, drone operators, airports, air traffic control and public agencies serving global aviation communities.

In the context of the new European regulations1 on drones, there has also been a push toward supporting systems that are able to help monitor the positions of drones and to provide a service that supports access to airspace without relying on temporary segregation techniques that can inconvenience other airspace users. This depends on the deployment of GNSS as the only ubiquitous Position Velocity Time (PVT) solution available in drones due to size and power constraints - and is also the case for certified drones, although they may also depend on traditional terrestrial based aviation solutions.

These applications enabling drone traffic management are also underpinned by GNSS positioning on smartphones and within the drones themselves. This supports the planning and execution of missions. These operate similar to the 'moving map' applications used today by manned aviation and are designed to help users understand and avoid temporary and permanent airspace restrictions.

The planning and execution of missions also needs to account for operation risk based on location, such as obstacles to aviation in the vicinity, risks from overflight, and proximity to people and property. This relies on accurate, up-to-date information which itself can be dependent on frequency of satellite-based mapping and identification of specific features.

Earth Observation data supports GNSS based applications

All aviation depends on reliable positioning information, both in terms of current location and direction of travel. GNSS has made this information more intuitive across the whole industry, especially with the introduction of moving map displays. At International Civil Aviation Organisation (ICAO) level the requirements for terrain and obstacle data to be available electronically have started to shift focus toward utilising satellites for data acquisition. Today, this satellite-derived topographical data enables all flight procedure analysis, particularly with regard to safety in relation to any proximate terrain or obstacles.

Further benefits have been realised in the aftermath of volcanic eruptions, showing the value of utilising satellite data to avoid ash clouds, protecting aircraft engines from possible inflight failure. GNSS proves equally relevant and beneficial in the industry from an environmental perspective, supporting assessment of aviation emissions and sustainability and local aerodrome impacts such as land and flooding risks, airfield air pollution and environmental planning.

The use of EO coupled with GNSS-derived data by drones supports collision and population risk assessments and is more important in the more dynamic environment in which drones may operate compared to traditional aviation. More frequently updated datasets, derived for aviation purposes, are essential to allow planning of aviation infrastructure, development of databases for map-based systems (e.g. moving maps, Unmanned Aircraft System Traffic Management (UTM) and terrain avoidance systems) coupled with GNSS data for positioning in relation to maps, flight procedure design and surveillance infrastructure. Procedure design and placement of surveillance infrastructure such as radars, terrain and obstacles (trees, buildings, etc.) are essential information that is used in pre-implementation assessments.

Within the aviation segment, European and North American organisations continue to dominate manufacturing of GNSS receivers for aviation (>95% of the market) in 2019 with North American receiver suppliers supplying 85% and European suppliers 14%.

The picture is more mixed when it comes to drones, with shares depending on the sophistication of the drone platform. Overall the Asian share is 47% with the European share at 10%.

GNSS capabilities are growing to meet evolving requirements for navigation, surveillance and sustainability (figure 2).

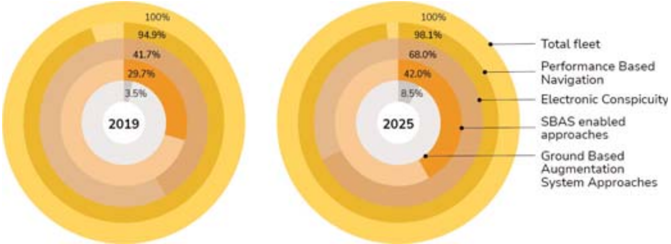


Figure 2. GNSS capabilities as a proportion of total civil aviation fleet

Dual Frequency Multi-Constellation progress in navigation

The GBAS Approach Service Type D (GAST D), which allows Cat-III precision approaches to less than 100ft height, is fully standardised and validated for GPS L1 signals. Furthermore, a dedicated ICAO ad- hoc group is defining the future DFMC GBAS concept, which takes benefit from dual-frequency signals and multiple constellations such as GPS and Galileo, in order to enhance the robustness of GBAS approach service and even explore new GBAS services. The ICAO DFMC GBAS Concept Paper is expected by the end of 2022.

As of today, it is expected that the GNSS Manual (Doc 9849) will update to accommodate GAST-F in 2024 and that ICAO Standards And Recommended Practices for GBAS GAST F would be written around 2030.

GBAS GAST F or GBAS DFMC is seen as the future of GBAS and will enable greater robustness against ionosphere disturbances as well as against Radio Frequency Interference (RFI), as it will work with two frequencies and offer reversion modes.

The ICAO Navigation System Panel (NSP) approved new Standards and Recommended Practices for the use of EGNOS and Galileo in November 2020. This is an important milestone in SBAS DFMC Standardisation for EGNOS and Galileo but also for European aviation. Indeed, DFMC SBAS opens up new possibilities for air transportation but also more resilience for users against RFI.

In the U-Space and UAM area EUSPA has supported numerous trials of drones equipped with EGNOS as well as Galileo through its EGNSS4RPAS project. Manned aircraft are expected to be outnumbered by all kinds of drones, employed for everything from weather and environmental monitoring to personalised delivery services. The traditional person-based air traffic control model will need to evolve to accommodate such a shift, based on automated monitoring, traffic management and collision avoidance. In Europe, this highly automated version of air traffic control is termed U-Space.

GNSS performance requirements supporting drone operations are being developed globally. Eurocae WG-105 within Europe is developing minimum operational performance specifications (MOPS) for Detect and Avoid (DAA) in Very Low Level (VLL) airspace.

SBAS's safety-of-life service is essential to making this happen, moving from today's situation - where drones are limited to specific air corridors and line-of-sight operations - to let them roam freely but safely in busy airspace and built-up areas.

Electronic Conspicuity is an umbrella term for technologies that provide self-reporting of position from an aircraft to other aviation actors. Electronic Conspicuity can be considered in two groups: Certified (used in controlled airspace by users such as commercial aviation and certified category drones) and Uncertified (used outside controlled airspace typically by General Aviation). It is also an essential enabler for U-Space as the means to provide the ability to 'detect' other aircraft. No solution has yet been agreed to enable interoperability between U-Space and manned aviation, but GNSS positioning reporting is enabled through the established ADS-B and a mix of proprietary solutions gaining traction with some users. There are several solutions including Automatic Dependent Surveillance Broadcast (ADS-B) (1090MHz and UAT), Flight Alarm (FLARM), LTE/5G and 802.11 raising questions on interoperability.

ADS-B implementation, both airborne equipage and ground infrastructure, continues toward full integration in the ATM environment. Since December 2020, new aircraft are required to be ADS-B equipped with a transition period till June 2023 for retro-fit. At European level, users would like to improve cost-efficiency through rationalisation of the surveillance infrastructure, including the decommissioning of CNS facilities and to improve the aviation spectrum efficiency. GNSS will become more critical as this step progresses.

The exploitation of GNSS timing as a reference source for timing and synchronisation processes is fundamental for critical infrastructure like telecommunication networks, energy distribution grids, financial markets and commercial aviation systems and networks.

In the case of aviation, optimising the traffic flows also comes down to timing, as does synchronisation of information about flights. This information can be shared between users to cut down on flight times and reduce delays, diminishing the environmental impact. GNSS time is used for:

- positioning and timing for on-board navigation purposes;

• timing and synchronisation for datalink c mmunications (on-board to ground and vice-versa); and timing and synchronisation for ground systems used for Air Traffic Control (ATC), communication networks, airspace surveillance, and airport logistics coordination.

Aviation needs advanced GNSS and new alternative PNT solutions

Traditional aviation has always operated with alternative technologies, particularly ground-based navigation aides, in addition to GNSS. Whilst these technologies cannot deliver the performance equivalent to GNSS, particularly with DFMC, they do provide resilience.

With interoperability, new airspace users expect a continued push for rationalisation of historical alternative technologies in the future, there will be a need to maintain a spectrum and cost-efficient solution accessible to all, drones and manned aviation alike. Technologies such as the L-band Digital Aeronautical Communications System (LDACS) and 5G offer integrated positioning services, yet there is no clear solution that can meet the key performance requirements that GNSS delivers.

In 18th November 2020, EUSPA and EHA (the European Helicopter Association) hosted a workshop on the GNSS/EGNOS benefits for Helicopter Emergency Medical Services (HEMS) operations. This builds on the increasing importance of GNSS to support helicopter operations operating in hostile environments, such as close to mountains or in valleys with poor connectivity to traditional infrastructure.

In addition, the use of GNSS-based altitude can provide specific benefits for helicopter operations under particular conditions:

• GNSS-based altitude can be used instead of bar metric altitude to improve altitude information reliability in low-level operations in areas where the local settings for barometric altitude (QNH) are not available or not reliable.

• errain Awareness Warning Systems (TAWS) and Synthetic Vision Systems (SVS) data is based on GNSS altitude. If the altitude displayed in the helicopter cockpit were GNSS-based instead of barometric, then all data would have the same reference and be coherent.

• At low speeds, the rotor flow can impact bar metric sensors, which can lead to some bias on barometric altitude determination. On some helicopters, a hybridization of GNSS-based altitude with barometric altitude is already made to reduce noise and bias in the altitude value.

The global drone market will grow from 19.4 bn in 2020 to over 36.9 bn in 2025 at a CAGR of 13.8%1.

This huge growth will drive shipments of GNSS-capable drones to exceed 10 million units per year for most of this decade, as shown in the chart below. The proportion of drone service revenue attributed to GNSS is shown in the adjacent chart.Nearly all drone use cases will continue to be operated outside of controlled airspace by Open or Specific category drones. Certified Electronic Conspicuity and Performance Based Navigation devices will be used for high-value applications, but by a relatively small population (compared to the overall drone market) of Certified drones.

Applications such as critical infrastructure inspection and drone Delivery & eCommerce - which is predicted to be the largest market area by 2030 - are developing rapidly. These applications increase demand for Beyond Visual Line of Sight (BVLOS) missions classified as medium risk, which will fall under the Specific category. Such missions require a proportionate approach to safety and will require a design verification report. The designs will almost certainly include Electronic Conspicuity devices (uncertified as they will be outside of controlled airspace) to ensure awareness of other airspace users, and support U-space tracking by UTM systems.

Urban Air Mobility (UAM) is a concept looking for ways to quickly and efficiently move people within cities in a safe and environmentally friendly manner. UAM transport networks will offer an alternative to congested city transport systems and will develop strong interfaces between city/region, drone, transport and urban planning communities. UAM is expected to debut in the coming years in big cities such as Paris and Singapore, according to Volocopter and Lilium, two European leaders in this market. UAM is not expected to emerge as a significant market until the 2030s.

As in most transportation modes, UAM strongly benefits from the GNSS services for positioning, but also from other services that are specifically tailored to drones applications: geo-fencing and geo-caging; e-identification (Drone navigation and guidance); and tracking (facilitated via Electronic Conspicuity). Maps that integrate EO data will provide up-to-date information about the distribution of dwellings and approximate population. This will help planning routes for UAM traffic to avoid densely populated areas and for developers to strategically plan infrastructure.

The Solution for EGNSS U-Space Service (SUGUS) project, funded by the European Commission, organised a survey last year, whose results can be used as a valuable input to tailor the EGNSS Service Provision layer to specific drone missions' needs, allowing better mitigation of risks in complex operations like UAM, increasing safety and security.

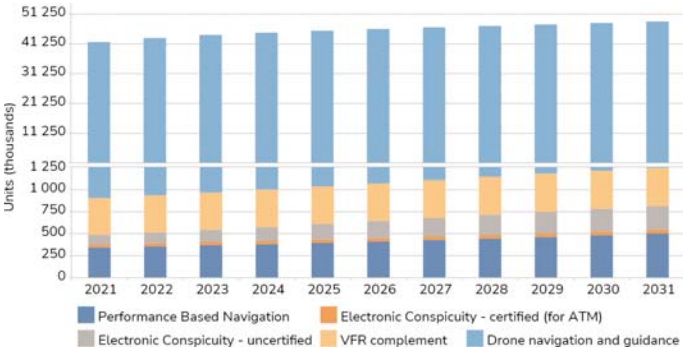


Figure 3. Installed base of GNSS devices by application

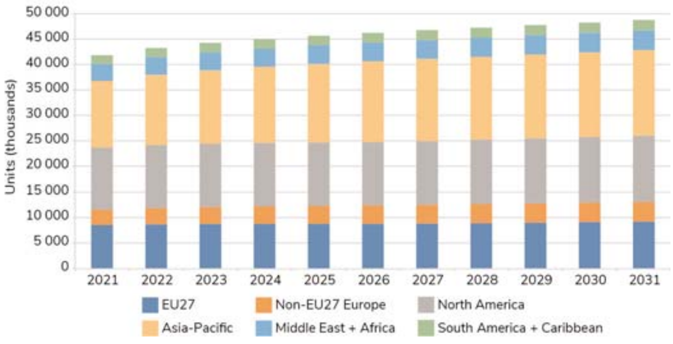


Figure 4. Installed base of GNSS devices by region

Successful economic development of the Arctic zone is impossible without the creation of a continuous information field covering its entire territory and accessible not only on stationary objects, but primarily on mobile vehicles - ships, vehicles, aircraft, etc. [9,10] The information field means the transmission of audio information (broadcasting programs), data (weather maps, ice conditions, etc.), navigation signals, alerts and information about emergencies, as well as other service information in the interests of various departments. Given the harsh climatic conditions, the reliability of information support directly determines the safety of human life in the Arctic. To ensure the required level of reliability, it is necessary to use at least two parallel operating and duplicating each other systems - the main and backup, based on different principles of operation.

Obviously, the information support of mobile objects can only be implemented using various radio systems. (Solutions for stationary objects are more diverse and are not considered in this article). It is also clear that, in most cases, large-sized and spatially oriented antenna systems cannot be installed on mobile objects. For this reason, even in the middle part of the Arctic zone (at latitudes above 75° and up to 81°), where the geostationary orbit (GSO) is observed very low above the horizon and only a small part of it is visible, on which satellites of the necessary operator are not always present, providing information field using GSO

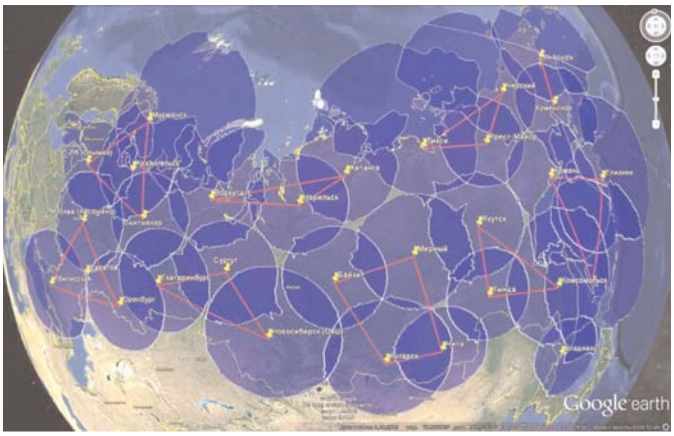


Figure 5. An example of the state digital radio broadcasting network architecture of Russia in LF range

satellites is not possible. From approximately 81° to the poles, the GSO is not visible from the Earth's surface, even theoretically.

The most promising for the formation of the main information field in the Arctic zone can be considered satellite systems located in highly elliptical or low orbits. At the same time, the high cost of such systems, the long period of infrastructure deployment and limited service life, combined with the low population density in the service area, determine their planned unprofitability and the need for budget financing.

As a backup means of forming the information field, it is advisable to consider terrestrial digital broadcasting systems [5-8]. By providing broadcast data rates comparable to those available for omnidirectional antenna reception in satellite systems, modern terrestrial digital broadcasting systems can be significantly more economical to deploy and operate. Prior to the commissioning of the satellite segment (in HEO or in low orbits), ground facilities can successfully perform the function of forming the main information field.

Many countries have chosen the European digital broadcasting technology platform, the digital broadcasting or digital sound broadcasting and DRM systems. Was investigated the possibility of using the DRM system at frequencies below 30 MHz. The completed studies confirmed the standard specifications for digital broadcasting or digital sound broadcasting and DRM systems [11-13].

IV. SPACE

Although GNSS was originally designed to serve terrestrial users, it has also proven its worth as a valuable tool in space. Within the last decade the space industry has experienced a profound transformation. Driven by technological advancements and a new entrepreneurial spirit, the space environment is now hosting an increasing number of platforms and has therefore become a new playground for GNSS technologies.

Whatever the mission type (telecommunication, Earth observation, scientific development, navigation, etc.), providing reliable real-time GNSS data to Earth-orbiting satellites can bring many financial, technical and societal benefits such as reduced mission costs, improved navigation performances and the provision of trustworthy EO data.

The launch of Low Earth Orbits (LEO) megaconstellation projects has become a symbol of this new era, showcasing incredibly diverse commercial possibilities such as EO in particular, but also in Satellite Communication for broadband connections and the Internet of Things (driven by the needs of global coverage and low latency). This phenomenon is inevitably leading to an unprecedented number of satellites orbiting the Earth and calls for new performance needs. GNSS has a major role to play in this evolution, thanks to the financial and technical benefits it brings (e.g. reduced number of instruments, reduced dependence on ground-based stations, improved navigation performances, etc.) and its applicability to both historical and emerging stakeholders.

Entering the third millennium, about 800 satellites were actively orbiting the Earth. Twenty years later, this number has exceeded 3,500 satellites and is expected to quadruple over the next decade. Outer space has become unbelievably crowded and the risk of collision between space objects statistically increase with every new launch.

Although all space users operate in a similar environment - i.e. outer space - many variables actually come into play when identifying case-to-case GNSS requirements.

Depending on their characteristics (e.g. mass, designed lifespan, mission type, mission costs, etc.) and the orbit they are targeting (due to variable geometrical constraints and signal availability), spacecraft are indeed not expected to be equipped with the same kind of spaceborne GNSS receivers. At relatively low altitudes (3,000- 8,000 km), GNSS receivers generally benefit from a good signal availability from any single constellation.

On the contrary, high altitude (8,000-36,000 km) are much more challenging as they often have to cope with a significantly reduced GNSS signal availability and therefore need ultra-sensitive receivers (i.e. able to exploit GNSS signals first side lobes) which are at the cutting edge of current technology. Also, large satellites can embark relatively heavy receivers (a few kilogrammes) while SmallSats must avoid this extra mass. Similarly, most CubeSat missions cannot afford expensive pieces of equipment while long-term missions are ready to do so to guarantee system robustness.

To tackle the space debris issue and avoid its escalation, mitigation measures and remediation services are today being considered and entrusted to the EU SST Consortium through the new Space Regulation. From the definition of post-mission disposal guidelines, to regular spacecraft evasive actions or the development of cutting-edge space debris removal technologies (e.g. robotic arms, harpoons, nets), some of these measures require the use of accurate positioning systems, representing a real opportunity for the spaceborne GNSS market.

The Astroscale ELSA-M spacecraft which aims, for example, to remove multiple retired satellites from LEO in a single mission, will use the off-the-shelf 'Constellation On Board Computer' (cOBC) GPS and a Galileo-enabled RUAG GNSS receiver. Astroscale announced a funding award from OneWeb, to mature their technology and capability towards a commercial service offering by 2024.

In 20 years, such systems might be used to bring space debris into dedicated recycling stations, in order to reuse part of their materials and components - these will rely on Galileo- based positioning systems.

Europe dominates the market for GNSS Components and Receivers, with a share of 73%, ahead of North America's 21%, in 2019, thanks to a combination of both historical stakeholders and new actors answering NewSpace needs. Led by Airbus, Hexagon and U-Blox, European companies hold six of the top 10 positions among manufacturers in the market.

Resulting from an ever-increasing adoption of GNSS-based solutions among the space users and the continuous development of new megaconstellation projects, the number of spaceborne GNSS receivers to be sold is expected to progressively increase in the coming years. The variable levels of certainty on the long-term success of these megaconstellations however prevent from properly assessing their potential replacement cycles and the impact it could have on the market on the second part of the decade.

High-end receivers are and will probably remain for the next decade the main option for most Space applications (except for technology development, due to their high cost). Yet, it is expected that Low-end receivers - which are today mainly used to support specific scientific or operational satellite missions, or for space timing and synchronisation - may significantly expand to Attitude Determination and Precise Orbit Determination applications, covering a growing part of LEO needs. As of today, two reasons suggest that these estimations with of future Low-End unit sales are conservative. First, only megaconstellations with granted FCC filings were captured within the model and no satellite replacement was included. Second, the CubeSat market might be slightly underestimated, since reliable data on forecasted university/academia missions are not available.

New actors are however not expected to replace historical ones, but to challenge and complement them. The technological push that has always defined the space industry is now strengthened by the user pull generated by new stakeholders' arrival and the need they create. Most of the new small LEO satellites are coming out with a need for GNSS receivers. With a relatively short lifetime and therefore a higher replacement rate, these satellites stand as the key driver of the spaceborne receivers' market. The technical adaptations required to evolve in this space environment are well-known and technically mastered in these low-altitude regions. The GNSS market for LEO satellites is therefore mature and several companies already propose off-the-shelf products (e.g. SSTL, GOMspace, Thales Alenia Space, etc.).

Software-defined receivers constitute a very interesting approach for space users, offering features such as re-programmability (i.e. upgradeability) or self-healing capabilities. The most vivid examples could be the possibility to upload algorithms yet-to-be-invented at the receiver's launch time, or the ability to recover from a single-event effect by remotely rewriting damaged functionalities, reducing the need of onboard redundancy.

Launched late 2017 by the GSA and led by Qascom, the ENSPACE (Enhanced Navigation in Space) project has recently developed an innovative GNSS spaceborne receiver. Targeting the needs for robust positioning, navigation and timing of satellites with the flexibility of a software solution, the ENSPACE technology fosters the use of GNSS in space. Configurable for multiple applications (e.g. navigation in space, timing determination, precise orbit determination, attitude determination) and diverse mission contexts (from Earth orbits to space exploration), ENSPACE aims to become a reference low-cost product on the market.

Three years after the project kicked-off, ENSPACE Receiver was integrated in a NASA/Ohio University 3U CubeSat(BOBCAT-1) and deployed from the ISS on the 5th of November 2020, with three main objectives: test the receiver in a real LEO space environment; assess its ability to continuously compute PVT information; and exploit its reconfigurability. Two weeks after its deployment, the ENSPACE receiver successfully computed BOBCAT-1 in-orbit first positions, combining GPS and Galileo signals. While the ENSPACE project has now come to an end, space experimentation and operations continue, including GNSS positioning with ground Assistance Data and the validation of the receiver's Attitude Determination, POD and Authentication algorithms.

In addition to the physical deployment of the receiver in space, the ENSPACE project has set up an innovative test platform, offering multiple experimentation possibilities for innovative space concepts and Galileo added-value. The platform was especially used to demonstrate the capability of the software-defined radio ENSPACE receiver, which was able to track the signal of the Spirent constellation simulator and to propose a real-time multi-constellation PVT solution in multiple space scenarios. In 2021, the ENSPACE receiver has a Technology Readiness Level (TRL) of 7 (i.e. a system prototype demonstration in operational environment). On the market it will take the commercial name of QN400.

With the GEYSER (GalilEo cYber SpacE Receiver) project, Qascom and its consortium are committed to follow in ENSPACE footsteps.

GEYSER complements developments over the past few years with new added-value functionalities, with the objective to become a close-to-market space receiver, and compatible with COTS. Targeting new applications (e.g. cybersecurity and robust PNT, dual-frequency POD for station keeping and collision avoidance, high dynamics navigation, etc.), the GEYSER project aims for new technological development targets, both on software and hardware levels.

In-orbit satellite (IoS) servicing refers to the refuelling or the repairing of space satellites while in orbit. Although considered since the early days of spaceflights, the recent easier access to LEOs and space debris-related issues has generated a renewed interest for the practice.

IoS has the potential to open-up new opportunities through satellite life extension, robotics and salvage, while also offering sustainability benefits through debris removal and material recycling over the longer term. While GNSS could be used as a mean of absolute (for the approach) and relative (for the connection) positioning, it is also suggested that IoS services may go beyond life extension and up to service enhancement, by providing additional capabilities to the client satellite (e.g. equip an already flying satellite with a new piece of hardware, such as a GNSS receiver).

The characterization of an interoperable GNSS Space Service Volume (SSV) - which is an important enabler for new missions and a key driver for new technological developments - is today limited to Earth orbits up to an altitude of 36,000 km (i.e. GEO). Yet, navigation is also a key technological enabler for cislunar and lunar volume discovery, and all the moon exploration missions that define the emerging lunar economy share similar navigation needs. The international space community plans therefore to extend GNSS PNT applications up to the Moon. Different phases could be considered, starting with the use of the already existing Earth- GNSS constellations via high-sensitivity space receivers, leveraging the use of GNSS signal side lobes. Yet, such approach only allows to reach cislunar areas (not occulted by the Moon). Plus, if the objective is to get enough accuracy and availability to enable autonomous landing and rover guidance, Earth GNSS signals alone are not sufficient.

Therefore possible to consider that Earth-GNSS constellations may be augmented with dedicated lunar orbiting satellites and lunar beacon ranging sources, marking a gradual deployment leading to a full autonomous lunar navigation system. Beyond the primary navigation purpose of such an ambitious system, any other GNSS-based applications could also be considered, such as the study of lunar soil deformation based on GNSS-R [2].

Currently, a number of "traditional" applications of global navigation satellite systems (GNSS) have emerged:

- services on mobile devices for a wide range of consumers - car navigators, navigators for walking man, fitness trackers, taxis, etc.;
- personal navigation (smartphones or specialized trackers);
- transport telematics (M2M) - monitoring of vehicles (movement control, fuel control, monitoring of various telemetry);
- navigation support of various moving objects (land transport, air and water craft);
- tasks requiring high-precision positioning (geodesy, cartography, monitoring of structures, coordinate farming, etc.);
- emergency response systems in case of accidents;
- military tasks and others.

There are new applications of GNSS. This is due to the "digitization" of the economy, production and all areas of our life [14, 18].

The GNSS positioning results are used in:

- automation of production, performance of works and provision of services;
- accounting of work performed and services rendered.

GNSS positioning penetrates into various information systems (personnel management, enterprise, accounting).

There are problems of seamless navigation and the use of combined positioning methods.

When solving problems of transport telematics, there are problems of monitoring new types of objects, as well as monitoring and control of an extended set of object parameters (which is especially important for special equipment).

Several new applications of GNSS technology:

- Employee monitoring system in the "Outdoor & Indoor" mode;

- Car monitoring system on the territory of the maintenance station;

- Monitoring system for performers at the airport;

- Monitoring of floating signs;

- Evaluation of driving styles.

The quality of a tourist trip depends on many factors, for example, GPS navigation and one of the essential is route consistency [19-21]. This geographical factor influences the popularity, efficiency and tourist travel safety. Considering usefulness of reference routes for the sports tourism development, one can assume their feasibility at the present time, when the goals of tourism, its organization system, and geographical directions of tourist flows are changing sharply.

Including 5G as a technology has the potential to have wide-ranging effects on the V2X ecosystem. To take full advantage of its capabilities, operators and industry leaders must familiarize themselves with the tools that modern cellular networks provide and understand how these tools can best be applied in end-to-end solutions [22-25].

V. CONCLUSION

The diversification and the expansion of space users is of great interest to the spaceborne GNSS receivers market. Yet, the consequence it has on the space environment raises the question of the awareness system and traffic management policies it requires. NewSpace activities could indeed overwhelm current space flight safety processes, putting at risk space infrastructure and human spaceflight. Currently, no 'highway code' has been established in outer space by the international community.

Today, space traffic is mainly 'ruled' by the Outer Space Treaty - establishing that no nation may claim sovereignty over outer space (article II) - and the IADC space debris guidelines, that aim to limit the generation of space debris. This is and will therefore remain an international concern. Cooperation - on a global scale - offers an unprecedented opportunity to enhance the safety of active satellites, in order to preserve space operations and all the benefits it brings to the global economy and society. But although the enforcement of Space Traffic Management (STM) policies may soon become inevitable, its implementation is extremely complex for political (no sovereignty over outer space) and practical reasons.

Tracking potential collisions, notifying impacted parties and coordinating how they respond is still a largely manual process, which is not sustainable as the number of satellites grows. In the past, developing automated systems for a handful of satellites making a few avoidance measures a year was not worth the investment. Today, with the influx of new LEO satellites, handling avoidance measures manually no longer makes economic sense.

Paving the way towards the building of an international approach to STM, the European Commission has recently launched a new 'EU strategy for Space Traffic Management (STM)' flagship project. As announced in the Action Plan on Synergies between Civil, Defence and Space Industries, the project aims to develop STM rules and best practices, limiting the risk that non-EU standards become the norm and supporting the EU in its efforts to achieve technological sovereignty.

The question of the role GNSS solutions could play in this long-lasting process is legitimate. Traffic management requires a good knowledge of each vehicle positioning and attitude, based on standardised and robust technological solutions. The development of spaceborne GNSS receivers and their deployment at a wider scale could therefore be one of the building blocks toward future space regulations. These moreover must be formulated and implemented in the very short term to ensure both space users can safely operate their systems and terrestrial users can benefit from their associated critical services (e.g. navigation, telecommunication, etc.).

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