GALILEO HIGH ACCURACY SERVICE (HAS)

INFO NOTE

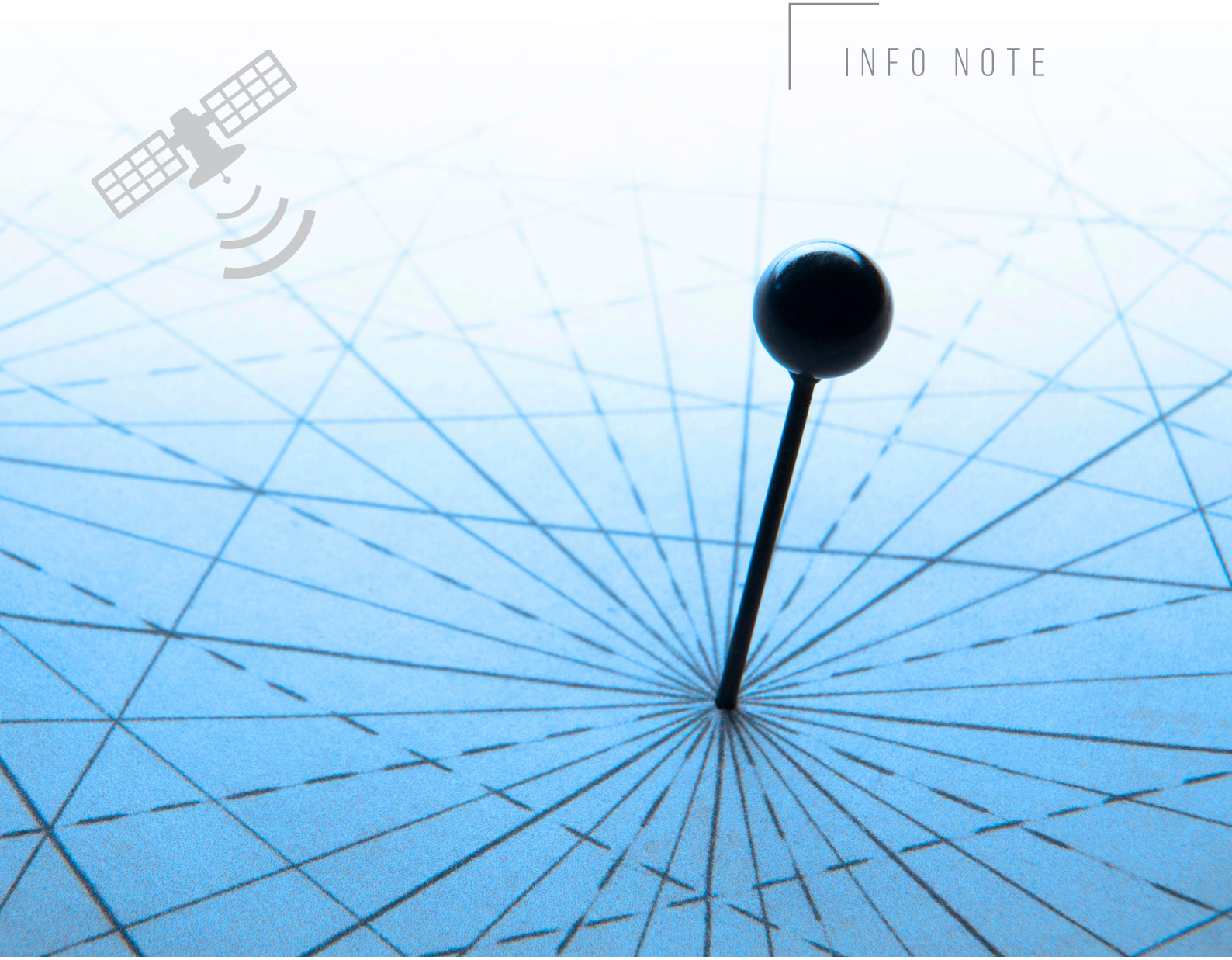

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

High-accuracy positioning services are understood as the services that allow users to achieve sub-decimetre level positioning accuracy. These kinds of services and their associated market are experiencing a massive uptick in interest thanks to the evolution of GNSS receivers and the rapid emergence of new applications requiring accurate location, which is making both equipment and services more affordable. Currently, high accuracy is mainly used in professional applications such as surveying, precision agriculture, civil engineering and geodesy, and is provided by the main GNSS augmentation service providers. However, new and emerging applications such as autonomous driving, unmanned vehicles (aerial, terrestrial and maritime), location-based services (LBS) or robotics are considered future potential markets.

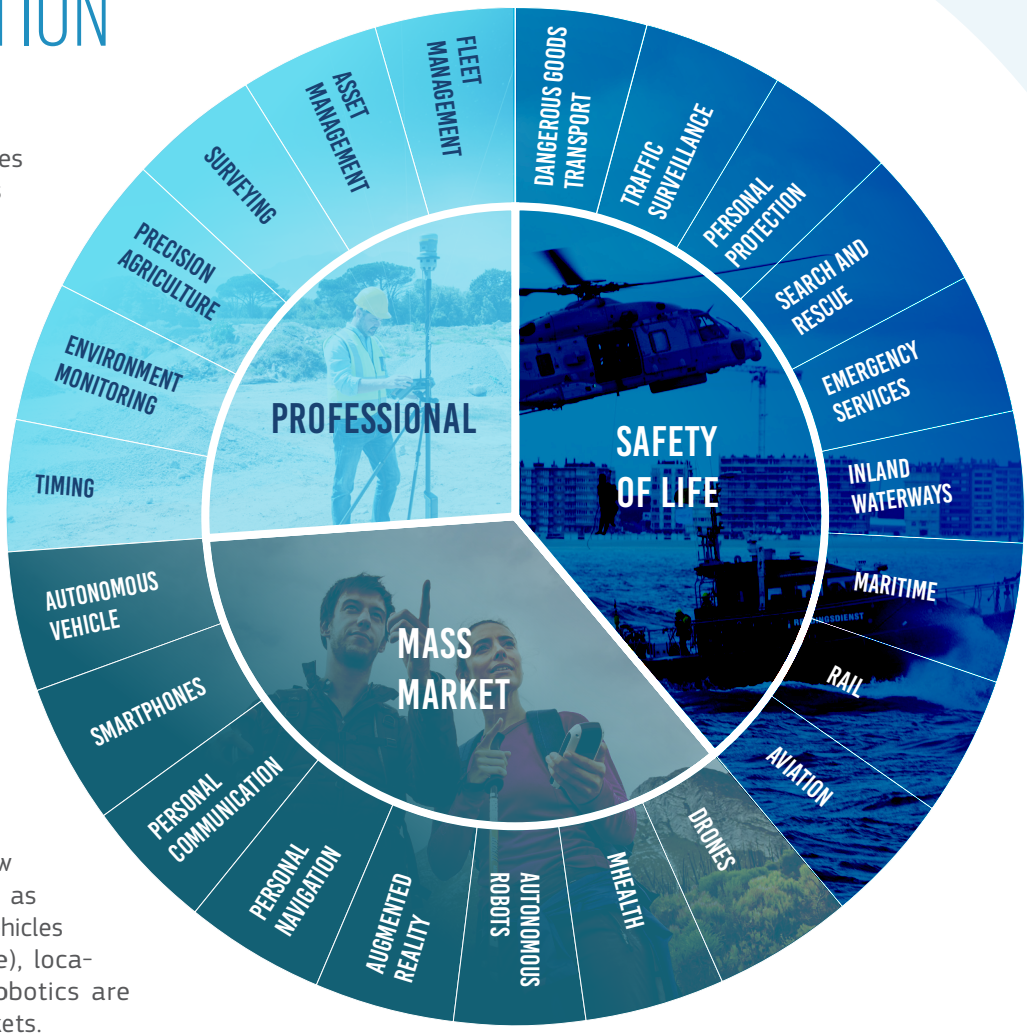


Figure 1: Examples of GNSS Applications

While GNSS enables many applications across multiple industries, the standalone accuracy provided is often not sufficient for professional applications such as precision farming, surveying or emerging applications such as autonomous driving, drones or robotics. Errors must be corrected to achieve high-accuracy positioning. Multiple technologies, such as PPP (Precise Point Positioning), RTK (Real Time Kinematic), and more recently PPP-RTK have been developed to achieve this. Network RTK (NRTK) is usually constrained by its operational model, which requires bi-directional communication, limiting the number of users and the area the network can support. PPP has no such limitation, but it requires long convergence times which typically do not align with user demands, in particular in the fast-moving consumer goods market (e.g., smartphones, IoT). PPP-RTK, however, addresses these shortcomings and is therefore a promising technology for consumer devices.

In order to address the high-accuracy needs in these markets the European Commission proposed the provisioning of a High Accuracy Service (HAS) through the Galileo programme, the European GNSS.

With HAS, Galileo will be the first constellation able to provide a high-accuracy PPP service globally directly through the Signal in Space. Typically, high-accuracy services are based on the provision of accurate satellite data (clocks, orbits and biases) and atmospheric data (mainly ionospheric and tropospheric corrections) on a regional level. For Galileo, high-accuracy data will be transmitted using an open format in the Galileo E6-B signal and via the internet.

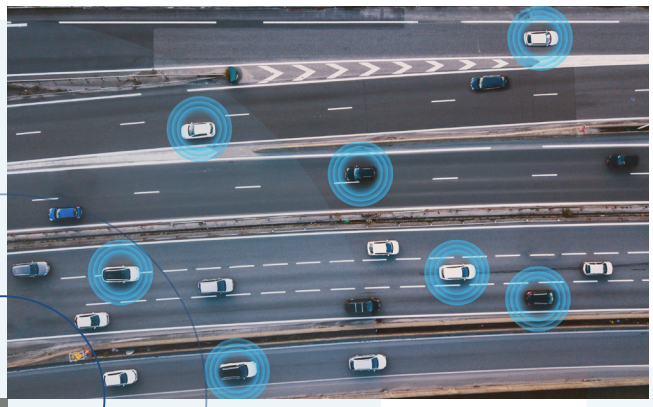
This paper provides an overview of the Galileo HAS service, covering its main characteristics and features such as service levels, target performance, its planned implementation roadmap, milestones and an overview of the addressable markets.

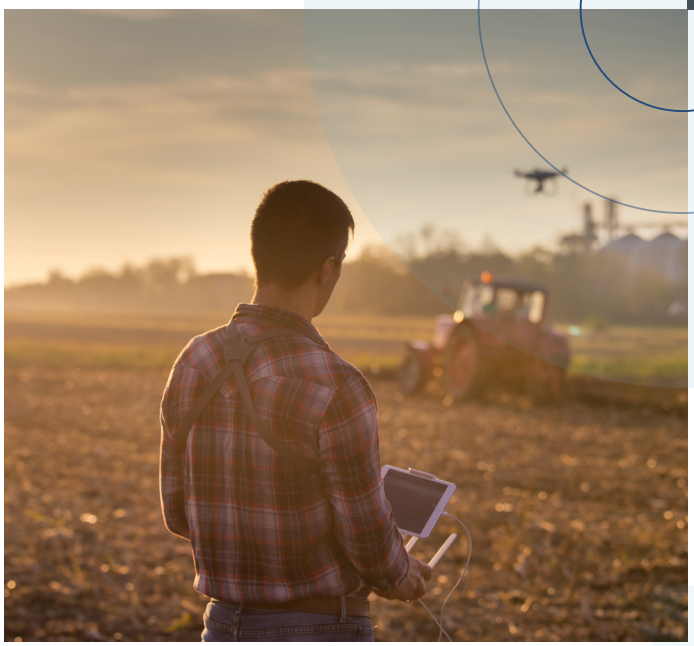
2. TARGET MARKETS

The high-accuracy positioning market is very dynamic, currently driven by emerging applications such as autonomous vehicles and drones, but also by technological evolution (e.g. dual-frequency chipsets for the mass-market) and the market situation (cheaper or free-of-charge services in some countries), all of which is leading to the democratisation of high accuracy. Therefore, high accuracy is not only a domain for professional applications but is becoming a widespread commodity.

The right solution for a high-accuracy application is typically a trade-off between many factors such as requirements for accuracy, coverage, convergence time, integrity, price, user support, and also the operational complexity to implement the solution. An accuracy of less than two decimetres is assumed to be sufficient for a wide array of emerging applications. This is the level of accuracy provided by the Galileo HAS, differentiating it from the niche centimetre- or millimetre-level applications addressed by commercial providers.

The GSA is regularly collecting inputs from user communities through its User Consultation Platform, which is a part of a process developed at the GSA to collect user needs and requirements and take them as inputs for the definition of user-driven EGNSS services. The results have been compiled in a series of Reports on User Needs and Requirements[1] per market segment, which ensure GNSS services anticipate and meet user needs. In addition, in alternate years the GSA publishes its GNSS Market Report[2] and User Technology Report,[3] which provide in-depth analysis on GNSS global market and technology trends. Table 1 provides an overview of the most relevant applications that can benefit from the Galileo HAS.





1 https://www.gsa.europa.eu/gnss-applications/user-needs-and-requirements
2 https://www.gsa.europa.eu/market/market-report
3 https://www.gsa.europa.eu/european-gnss/gnss-market/gnss-user-technology-report

Table 1 - Overview of the most relevant HAS target applications

MARKETS	APPLICATIONS
 GEOMATICS	Geomatics is the segment with the most stringent accuracy requirements, but for certain applications dm-level is sufficient: • GIS/MAPPING • CADASTRE IN RURAL AREAS (LAND CONSOLIDATION) • HYDROGRAPHIC SURVEY • OFFSHORE EXPLORATION The performance offered by the HAS through E6b is expected to give a new boost to GIS applications, further supporting the creation of new services thanks to free access to high accuracy, from lane marking to utilities and points of interest connected to extended reality applications.
 AGRICULTURE	There is a wide range of precision farming applications for certain type of crops that can benefit from dm-level accuracy such as: • GUIDANCE • VRA-LOW APPLICATIONS • FARM MACHINERY POSITIONING • SITE-SPECIFIC DATA ANALYSIS APPLICATIONS These applications can be used for farming activities such as soil condition monitoring, cultivation, spraying, seeding and fertilising, etc. Also, HAS can be relevant for Common Agricultural Policy (CAP) applications, e.g. a geo-tagged photo app with 9 million EU farmers as potential users.
 AVIATION	GNSS's role is becoming more and more prominent, since automated drone functions are becoming increasingly accessible and a HAS service with 20 cm positioning accuracy can be relevant for the applications below. New airport surface management systems will also benefit from increased accuracy: • DRONES: POSITIONING SYSTEM (URBAN) • DRONES: NAVIGATION SYSTEM (URBAN) • DRONES: GEO-AWARENESS SYSTEM • AIRPORT – INTEGRATED SURFACE MANAGEMENT SYSTEMS Specialised functions such as "return to home" or flight planning are now available even in budget models, and for new emerging applications such as parcel delivery using drones with beyond line-of-sight, etc. the accuracy provided by HAS is desirable.
 ROAD	The accuracy requirement for the following applications in the road segment is in line with the target positioning performance of the Galileo High Accuracy Service (i.e. ~20 centimetres): • AUTONOMOUS DRIVING • SAFETY-CRITICAL APPLICATIONS However, these applications require additional critical measures, such as integrity, to ensure safe navigation. These will be provided by integrators and service providers integrating various sensors and navigation technologies (including GNSS) in a hybrid solution.
 CONSUMER SOLUTIONS	The addition of free high-accuracy positioning with dm-level precision can benefit the following applications in consumer solutions: • LBS • GAMING • HEALTH • AR FOR LEISURE • COMMERCIAL (GEO-MARKETING AND ADVERTISING) • AR PROFESSIONAL • ROBOTICS - HIGH GNSS USE For smartphones, HAS may enable a wealth of new apps, such as augmented reality. Robotics is widely reported to be one of the fastest growing market sectors, driven by the developing capability of robots to navigate complex environments thanks to local sensors such as LIDAR that are critical to understanding the robot's immediate surrounding but also, with the inclusion of GNSS sensors, necessary for open environment navigation.

MARKETS	APPLICATIONS
 **RAIL**	For the following rail applications, a horizontal accuracy from 10 cm to 1 m is needed, usually coupled with integrity: • COLD MOVEMENT DETECTION • ODOMETER CALIBRATION • DOOR CONTROL SUPERVISION • INFRASTRUCTURE SURVEYING • GAUGING SURVEYS • STRUCTURAL MONITORING Railways are the backbone of the EU transport system and, as such, they form a critical element of mass transportation that must maintain high safety standards within tight time constraints. The introduction of automatic train control systems has improved the efficiency of railways, complemented by the use of GNSS at the moment to track trains for non-safety relevant purposes even on low-density line networks. In the future, it is also planned to introduce GNSS as one of the ERTMS game changers for train signalling. High-accuracy services can further improve the performance of non-safety relevant applications and can reduce the need for additional sensors, helping to further decrease maintenance costs for both railway infrastructure managers and train operators.
 **MARITIME & INLAND WATERWAYS**	For the following maritime applications, a horizontal accuracy from dm-level to 1m is needed: • MERCHANT NAVIGATION IN PORTS • PILOTAGE OPERATIONS IN PORTS • PILOTAGE OPERATIONS IN IWW • PORT OPERATIONS • PORT BATHYMETRY • RIVERBED SURVEY • COASTAL SEABED SURVEY • OFFSHORE SUPPLY VESSELS WITH DYNAMIC POSITIONING • PORT TERMINAL CRANES AND STRADDLE CARRIERS NAVIGATION • AUTONOMOUS SURFACE VESSELS Waterborne transportation (passengers and cargo) and engineering operations will benefit in terms of efficiency and safety thanks to the increased level of accuracy provided by the HAS, especially in those applications where the cost of a three-frequency receiver and antenna is negligible in comparison with the savings in operational costs.
 **SPACE**	For satellites and space vehicles orbiting Earth, vertical and horizontal high-accuracy positioning is a key enabler for critical applications: • PRECISE ORBIT DETERMINATION (E.G. FOR AUTONOMOUS FORMATION FLYING AND IN-ORBIT RENDEZVOUS AND DOCKING) • ATTITUDE DETERMINATION • CIVILIAN LAUNCHERS (E.G. FOR PRECISE ORBIT INJECTION) The space industry has traditionally used expensive solutions (in terms of cost, power, and mass) for these applications. For military missions, they will have access to PRS for precise positioning, but there is a gap when it comes to civilian and commercial missions.

3. HAS SERVICE CHARACTERISATION

The HAS will provide free of charge high-accuracy PPP corrections, in the Galileo E6-B data component and by terrestrial means, for Galileo and GPS (single and multi-frequency) to achieve real-time improved user positioning performances (positioning error of less than two decimetres in nominal conditions).

The HAS comprises two services levels for global and regional coverage:

- Service Level 1 (SL1): with global coverage; providing high accuracy corrections (orbits, clocks) and biases (code and phase) for Galileo E1/E5b/E5a/E6 and E5AltBOC and GPS L1/L5/L2 signals.
- Service Level 2 (SL2): with regional coverage; providing SL1 corrections plus atmospheric (at least ionospheric) corrections and potential additional biases.

Table 2 summarises the HAS full service characteristics and main targets for both service levels (note that the HAS initial service will provide a reduced performance level, as described in section 5).

Table 2 - main HAS characteristics and target performances

HAS	SERVICE LEVEL 1	SERVICE LEVEL 2
COVERAGE	Global	European Coverage Area (ECA)
TYPE OF CORRECTIONS	PPP - orbit, clock, biases (code and phase)	PPP - orbit, clock, biases (code and phase) incl. atmospheric corrections
FORMAT OF CORRECTIONS	Open format similar to Compact-SSR (CSSR)	Open format similar to Compact-SSR (CSSR)
DISSEMINATION OF CORRECTIONS	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)
SUPPORTED CONSTELLATIONS	Galileo, GPS	Galileo, GPS
SUPPORTED FREQUENCIES	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C
HORIZONTAL ACCURACY 95%	<20 cm	<20 cm
VERTICAL ACCURACY 95%	<40 cm	<40 cm
CONVERGENCE TIME	<300 s	<100 s
AVAILABILITY	99%	99%
USER HELPDESK	24/7	24/7

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

In addition, the European GNSS Service Centre (GSC)[4] will deliver user support functions such as the provision of service status information, performance forecasts, incident management, and user helpdesk support. Furthermore, system and service performances will be regularly monitored by Galileo through an independent monitoring facility (Galileo Reference Centre - GRC) and by appropriate system tools.

4 https://www.gsc-europa.eu/

4. **HAS** HIGH-LEVEL ARCHITECTURE

The figure below provides a simplified view of the Galileo HAS high-level architecture, with the main elements involved in the broadcasting of HAS data based on the following Galileo system capabilities:

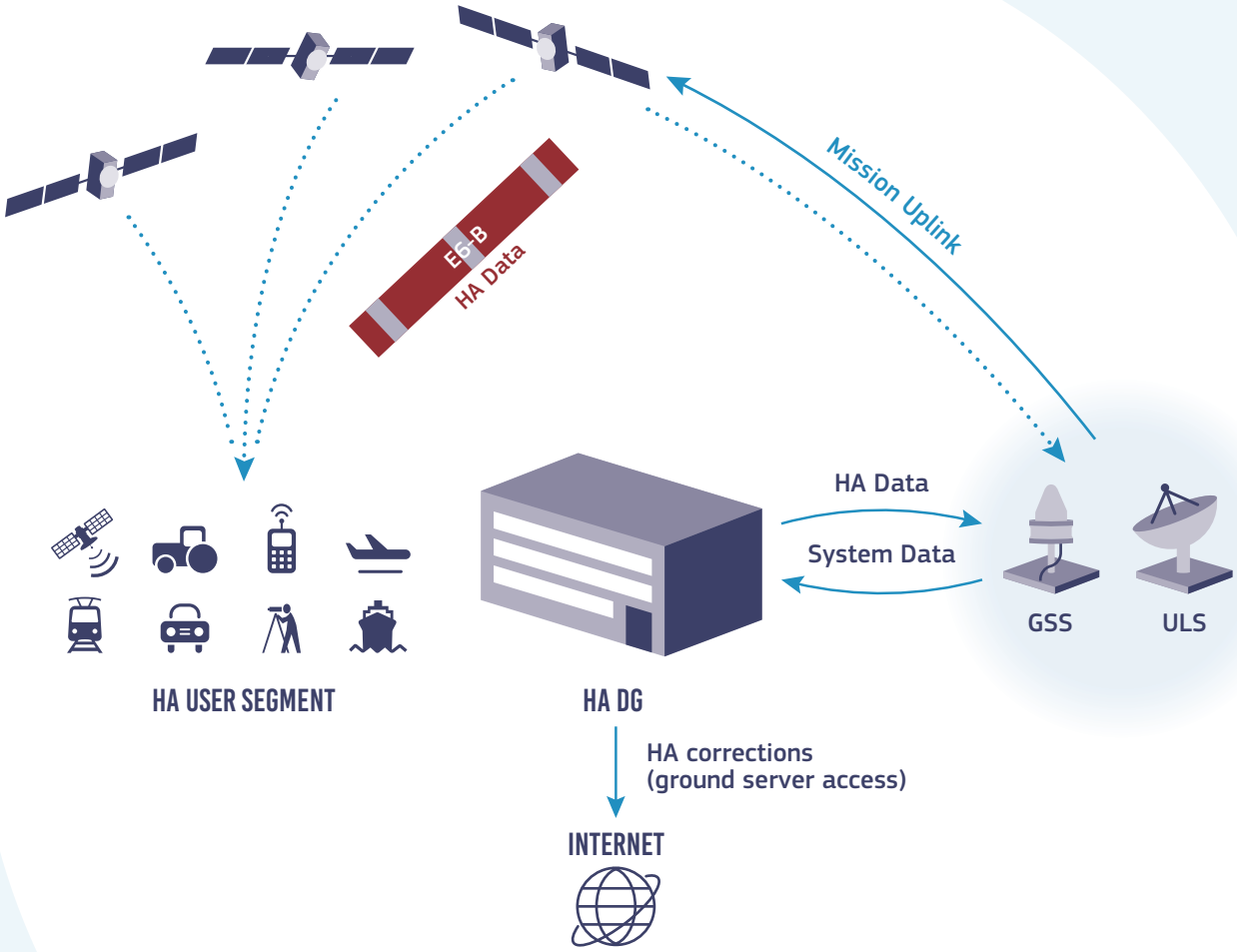
1. A high data bandwidth compared to other GNSS signals (448 bits per second per connected satellite in the Galileo E6B component).

2. The transmission of data through satellites connected to Galileo uplink stations on the ground.

The HAS corrections module will be in charge of the generation of the HA data that will be relayed in real time for its uplink and broadcast through the Galileo E6B signal component.

Galileo's capacity to broadcast high-accuracy corrections will evolve in line with the continuous deployment of infrastructure, driven mainly by the number of operational satellites, but also by the evolution of ground infrastructure.

Figure 2: Galileo HAS high-level architecture

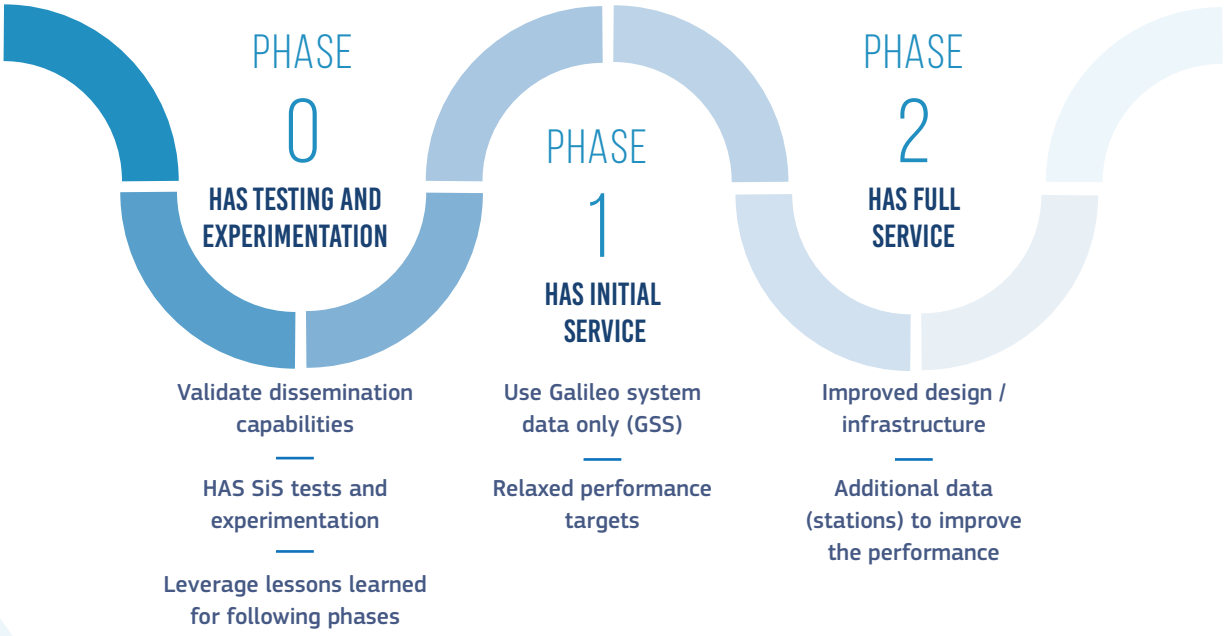


5. HAS ROADMAP

It is planned that the implementation of the Galileo High Accuracy Service will be staggered, based on the 3 phases depicted in Figure 3. The main elements and objectives of each phase are as follows:

- **Phase 0 (HA testing and experimentation).** Activities aimed at validating Galileo's dissemination capabilities through the E6B channel and performing initial high-accuracy testing. Internal testing is ongoing since 2019. HAS SiS tests are planned to be executed from Q1 2021, including the potential involvement of key stakeholders and interested parties under certain conditions (see Call for Expression of Interest in Table 3).
- **Phase 1 (HA Initial Service).** Provision of an initial Galileo High Accuracy Service resulting from the implementation of a high-accuracy data generation system processing Galileo system data only. The HA initial service will deliver Service Level 1 only with a reduced performance (below the full service's targets).
- **Phase 2 (HA Full Service).** Full provision of the Galileo High Accuracy Service, Service Level 1 and Service Level 2, fulfilling its target performance (e.g. 20 cm positioning performance).

Figure 3: Galileo HAS roadmap



In line with the Galileo HAS Roadmap, key milestones are planned to ensure continuous service development. Table 3 below shows the most relevant milestones with their corresponding tentative dates.

Table 3 - Next milestones and opportunities

DATE[5]	MILESTONE
2020	**User Consultation Platform** • The User Consultation Platform (UCP) is a forum for interaction between users of position, navigation and time solutions and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. The platform serves as a key tool for gathering user requirements and validating the Galileo HAS target performance • The UCP 2020 will be held during European Space Week on 7-11 December 2020 (https://www.euspaceweek.eu/)
2021	**Call for Expression of Interest** • Participating in the HAS SiS ICD public consultation • Expressing interest in participating in ad-hoc HAS SiS testing campaigns • Providing feedback on specific HAS user requirements
2021	**HAS PO Testing**
2021	**HAS SiS ICD Publication** • Following the finalisation of the testing phase, the first version of the HAS message specification document is planned to be published
2022	**HAS Initial Service Declaration** • After the necessary service validation activities, the HA Service will be declared available and the HA Service Definition Document will be published
> 2024	**HAS Full Service Operational Capability**

5 The dates indicated are tentative and subject to change

6. HAS RELEVANT DOCUMENTATION AND INTERFACES AVAILABLE

- Galileo E6-B/C Codes Technical Note: https://www.gsc-europa.eu/sites/default/files/sites/all/files/E6BC_SIS_Technical_Note.pdf
- For general information on Galileo: https://www.gsc-europa.eu/
- Galileo helpdesk: https://www.gsc-europa.eu/helpdesk/
- GSA Market Report: https://www.gsa.europa.eu/market/market-report
- GSA Technology Report: https://www.gsa.europa.eu/european-gnss/gnss-market/gnss-user-technology-report
- GSA Reports on User needs and requirements: https://www.gsa.europa.eu/gnss-applications/user-needs-and-requirements

7. SUMMARY

With the Galileo High Accuracy Service (HAS), Galileo will pioneer a worldwide, free high-accuracy positioning service aimed at applications that require higher performance than that offered by the Open Service. The HAS will be based on the provision of PPP corrections (orbit, clock, biases, atmospheric corrections), at a maximum rate of 448 bps per Galileo satellite connected to an uplink station, allowing the user to obtain a horizontal positioning error of less than two decimetres (95%) in nominal conditions of use. The parameters and the business model of the service will foster innovation in both consolidated and emerging markets, notably in key areas such as drones and autonomous cars, minimising disruption in the current business models of established providers.

The HAS will be implemented in three phases, including testing and experimentation; an initial Galileo High Accuracy Service for a reduced number of signals, with relaxed performance targets and a reduced coverage area; and a full Galileo HAS that will offer two service levels and global coverage. Service Level 1 will provide PPP corrections globally to achieve 20 cm horizontal precision with <300s convergence time, while Service Level 2 will additionally offer atmospheric corrections for Europe to reduce the convergence time to 100s.

Galileo, through the HAS, will offer a unique service with the transmission of corrections directly via Galileo satellites, allowing free high-accuracy positioning globally, for everyone.

ANNEX I – **HAS** R&D AND MISSION STUDIES

Emerging/next-generation applications will require improved positioning performance to offer innovative services in the future. The European Commission and the GSA are currently specifying the long-term evolution fo the EGNSS programmes, in close cooperation with the European Space Agency, including new services for Galileo and EGNOS in the 2030+ timeframe. Therefore, beyond the HAS Roadmap described in this document, the Programme is already targeting the enhancement of the HAS performance in the frame of the Galileo Second Generation (G2G) developments. Moreover the Programme has been launching a number of mission studies and R&D activities to explore and evaluate the potential evolutions of EGNSS high-accuracy services to complement and support the evolving needs of new demanding applications. These studies are only exploratory and do not imply the implementation of similar services in the future.

- **CESAR and GALCS Galileo Commercial Service studies (No 200/PP/ENT/RCH/12/6918):** Confirmed the technical feasibility and market opportunity of high accuracy as part of the Galileo Commercial Service. Projects finalised in 2014.

- **EGNOS HA Project (632/PP/GRO/RCH/17/9876):** Analyses potential user needs and the service provision for a High Accuracy Service in view of EGNOS V3 in the 2020-2035 timeframe. Project finalised by mid-2019.

- **AALECS project (ENTR/308/PP/ENT/RCH/13/7077):** Developed a HAS demonstrator and transmitted the first high-accuracy corrections to Galileo Signal in Space (2014). Project finalised in 2020.

- **H2020-ESA-044:** EGNOS next-phase 0/A study including a real-time SBAS PPP – EGNOS High-Accuracy with Integrity. Project to be launched in 2020.

- **No. DEFIS/2020/OP/0002:** R&D project to integrate and test a combined Galileo HAS/authentication real time platform. Project to be launched in 2020.

- **Integrity Service Complementing EGNSS High Accuracy (DEFIS/2020/OP/0005):** Analyses the feasibility of an integrity service complementing HAS in the 2030+ timeframe on top of the current baseline of EGNSS services to feed evolving needs in autonomous transport. Contract notice published on 9/2020.

- **Ongoing GSA HAS-related grants and procurements:**

FUNDAMENTAL ELEMENTS GRANTS:

  - *Development of GNSS receiver technologies for premium and general mass markets*
  - *Development of an Advanced Interference*
  - *Detection and Robustness Capabilities System*
  - *Receiver technologies for high-precision in the mass-market*
  - *Filling the gaps and emerging E-GNSS receiver technologies*
  - *Multi-frequency, multipurpose antenna for Galileo*

FUNDAMENTAL ELEMENTS PROCUREMENTS:

  - *Galileo High Accuracy Service (HAS) User Reference Algorithm and User Terminal*

ANNEX II – ACRONYMS AND ABBREVIATIONS

Table 4 - Abbreviations

ABBREVIATION	DEFINITION
AltBoc	Alternative Binary Offset Carrier Modulation
AR	Augmented Reality
CAP	Common Agricultural Policy
CSSR	Compact State Space Representation
ECA	European Coverage Area
ERTMS	European Rail Traffic Management System
FE	Fundamental Elements
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRC	Galileo Reference Centre
GSA	European GNSS Agency
GSC	European GNSS Service Centre
GSS	Galileo Sensor Station
HA	High Accuracy
HADG	High Accuracy Data Generator
HAS	High Accuracy Service
ICD	Interface Control Document
IoT	Internet of Things
IWW	Inland Waterways
LBS	Location-based Services
LIDAR	Light Detection and Ranging
MKD	Market Development
NRTK	Network Real Time Kinematics
PPP	Precise Point Positioning
RTK	Real Time Kinematics
SBAS	Satellite-based Augmentation System
SiS	Signal in Space
SL	Service Level
SSR	Space State Representation
UCP	User Consultation Platform
VRA	Variable Rate Application

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The European GNSS Agency (GSA)

The GSA's mission is to support European Union objectives and achieve the highest return on European GNSS investment, in terms of benefits to users and economic growth and competitiveness by:

- Designing and enabling services that fully respond to user needs, while continuously improving the European GNSS services and infrastructures;
- Managing the provision of quality services that ensure user satisfaction in the most cost-efficient manner;
- Engaging market stakeholders to develop innovative and effective applications, added-value 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.

Galileo

Galileo is the European Union's Global Satellite Navigation System (GNSS) that provides accurate positioning and timing information. Galileo is a programme under civilian control and its services can be used for a broad range of applications. It is autonomous but also interoperable with existing satellite navigation systems.

On 15 December 2016, the Declaration of Initial Services marked the beginning of Galileo's operational phase. This means that anyone with a Galileo-enabled device is now, in combination with other GNSS systems, able to use signals provided by Galileo's global satellite constellation for positioning, navigation and timing.

The fully deployed Galileo system will provide five different services:

- Open Service (OS) that targets the mass market. The OS offers either single (E1) or dual frequency (E1 and E5) and will be the first to broadcast authentication data through its Navigation Message Authentication (OS NMA).
- HAS (High Accuracy Service) will complement the OS and provide a higher positioning accuracy being broadcast on the E6-B signal component.
- CAS (Commercial Authentication Service) will make it possible to authenticate signals, by giving access to the E6 signal pilot component (E6-C) codes, which will be encrypted.[6]
- Public Regulated Service (PRS) will be dedicated to government-authorised users. It will be encrypted and secured against jamming and spoofing.
- Search and Rescue (SAR) service will allow near real time alert localisation and message detection, higher beacon localisation accuracy, high availability and global satellite coverage. It will have a return link, which is unique to Galileo, and will reduce the rate of false alerts.

useGALILEO.eu

Devices containing a Galileo-enabled chipset, such as smartphones or vehicle navigation devices, can use Galileo signals for positioning, navigation and timing. The www.useGALILEO.eu tool helps you find Galileo-enabled chipsets, smartphones, wearables and tracking devices.

6 According to the Commission Implementing Decision (EU) 2017/224 of 8 February 2017 setting out the technical and operational specifications allowing the commercial service offered by the system established under the Galileo programme to fulfil the function referred to in Article 2(4)(c) of Regulation (EU) No 1285/2013 of the European Parliament and of the Council CS comprises two major improvements – the High Accuracy Service and Commercial Authentication Service.

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