EGNOSHA FINAL REPORT

EGNOSHA

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DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	16/07/2019	39	First issue of the document, submitted for FR milestone.
1.1	30/09/2019	50	Document updated for FR-CO milestone. The following comments have been implemented: ■ Figure 3-3 has been updated. ■ It has been pointed that although E5b is allocated in ARNS, it can be used as EGNOS HA dissemination channel. ■ E5b modulation and bitrate have been added. ■ Section 3 have been restructured as proposed in RID-0008. ■ It has been pointed that the stations should provide GPS + Gal (2 frequencies for Initial SL and three for FOC). ■ Service Implementation Roadmap has been modified and updated as agreed in the FR. ■ It has been specified who is the actor in charge of the activities in the roadmap. ■ RISK 04 has been updated to cover all the technology that could not be mature (not only integrity). ■ RISK 10 and 14 have been merged. ■ Standardization have been split in system and user parts. ■ Footnote have been removed as all EGNOSHA deliverables are authorised for public distribution. ■ In the service definition: Two time to alert have been added (for user and service side); Vertical PL has been added; Continuity has been added; It has been pointed the difficulties to achieve the Integrity requirements. ■ Service Provider trade-off has been simplified. ■ It has been pointed the difficulty to define the environmental scenarios as one of the key open points ■ Risk tolerability has been updated ■ FR-GSA-EGN-JOG-0023: "Section" instead of "paragraph" used in the whole document; ■ FR-GSA-EGN-JOG-0024: Reference for Table 6-1 added; ■ FR-GSA-EGN-JOG-0025: Table 6-1 updated, reporting the addressable market for the overall period (2025-2035); ■ FR-GSA-EGN-JOG-0026: The meaning of "one-off cost for service implementation" clarified and examples added; ■ FR-GSA-EGN-JOG-0027: Rationale behind the main differences in terms of device/ equipment price for the diverse domains explained; ■ FR-GSA-EGN-JOG-028: Support to service provider(s) reviewed, explaining better the point and reviewing the wording; ■ FR-GSA-EGN-JOG-029: Suggestion (i.e. involvement of receiver manufacturers) added among conclusions.
1.2	21/10/2019	51	Final version of the document is issued. Executive summary and conclusions are added to the document

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1. INTRODUCTION

The Final Report of the EGNOS High Accuracy Service study (hereinafter called EGNOSHA) summarises the results of the work carried out by the EGNOSHA consortium to determine under what conditions it would be beneficial to implement an EGNOS High Accuracy service in the timeframe 2025+.

The project results represent the views of the users and the consortium. They do not necessarily represent the views of the European Commission and they do not commit the Commission to implementing the results.

1.1. HIGH ACCURACY SERVICES CONTEXT

High Accuracy positioning services are understood as the services which allow users to achieve decimetre and sub-decimetre level positioning accuracy. These kind of services and their associated market are experimenting a quick evolution and adoption in the last years thanks to the upcoming applications and technologies requiring these services.

High Accuracy services can be divided in "global", "regional" or "local", depending on the area and technology used for the service provision. Global services are based on Precise Point Positioning (PPP) techniques, whilst regional and local services are normally based on differential solutions such as Real Time Kinematics (RTK). Both PPP and RTK are quite different in terms of required infrastructure, CAPEX and OPEX. PPP uses a sparse global station network to generate HA information to provide a worldwide service plus a set of regional stations to improve the convergence time in specific service areas. On the other hand, RTK requires a dense station network in the service area as well as high bandwidth to disseminate the data generated by the RTK base stations.

High Accuracy services are being widely adopted thanks to the evolution of the GNSS receivers with better performance at affordable price and the fast emergence of new applications. Until now, High Accuracy services were mainly used for mapping & surveying, GIS, mining, maritime (i.e. oil and gas, surveying or dredging), precision agriculture, civil engineering and geodesy. Such service is currently provided by Fugro, Novatel, Hemisphere among others. New applications such as autonomous driving, unmanned vehicles (aerial, terrestrial and maritime), Location-Based Systems (LBS) or rail services are considered attractive markets for high accuracy.

The emerging of new market opportunities come together with new user needs and requirements (e.g.: need of integrity for liability and safety critical applications), new potential Service Providers (e.g.: Galileo HAS, Iridium, OneWeb, 5G) as well as new necessities in the user-segment for hybridisation of GNSS with other sensors (accelerometers, gyroscopes, odometers, magnetometers, barometers, Wi-Fi, pseudolites, LIDAR/cameras, radar, laser or map matching) to allow the provision of enhanced services, especially in harsh user conditions.

1.2. THE EGNOSHA PROJECT

The EGNOSHA project was an 18-month feasibility study funded by the European Commission (EC) through 632/PP/GRO/RCH/17/9876 and technically supervised by the European GNSS Agency (GSA). It started in January 2018 and finalized in July 2019. A consortium composed by GMV Aerospace and Defence and ALPHA Consult carried out the study.

The aim of the EGNOSHA project was to define and assess the feasibility of a High Accuracy service based on the future EGNOS V3 system and to analyse under which conditions it would be beneficial to provide the service over Europe after 2025. The work was organized and executed as follows:

- First, a dedicated study of the **High Accuracy user needs**, market forecast and competitive analysis was carried out. For this activity, the involvement of stakeholders of the value chain and the requirements validation was considered critical for the validity and credibility of the study, hence special emphasis was placed on the consolidation of the user's needs and on the validation of the results with the stakeholders from the targeted sectors.
- Once the user needs were validated, different High Accuracy technologies and evolutions for the 2025-2035 timeframe were analysed. As a result of these analysis a service provision scheme was

proposed and service requirements were specified. Finally, the consortium defined a **service implementation roadmap** and the activities on the critical path.

- Lastly, two **Cost Benefit Analyses** (CBA) were carried out: one to understand the added value of the EGNOS High Accuracy service from the user perspective and a second one to understand the value from the point of view of the service providers. Experts in several application domains contributed to the qualitative and quantitative results of the CBAs carried out by the consortium.

2. EXECUTIVE SUMMARY

This section summarises the main conclusion obtained by the EGNOSHA project related to the potential deployment and provision of a High Accuracy Service on top of the EGNOS V3 infrastructure. Following, the most relevant conclusions are presented:

- **Service definition:** An analysis of the users' needs has been performed and the obtained results have been translated into EGNOSHA service requirements. The EGNOS HA service could be developed into two steps, each characterised by specific performance, an 'Initial Service' (IOC) and a 'Full Operational' (FOC). IOC is a preliminary service with reduced performances whilst the FOC service targets more demanding performances and availability. Both services will cover EU28 countries and will provide Integrity information as the key differentiator of the service compared to other high accuracy services offered on the market. Table 2-1 summarises the main features of the proposed service levels:

Table 2-1: EGNOS HA Service description

User Performance	Initial EGNOS HA Service (IOC)	Full Operational EGNOS HA Service (FOC)
Positioning Daily Accuracy	<30 cm (horizontal 95%) <50 cm (vertical 95%)	< 5cm (horizontal 95%) < 10 cm (vertical 95%)
Convergence Time	< 20 min (95%)	< 2 min (95%)
Daily Availability	> 97.5%	> 99.9%
Daily Continuity	95.0% to 99.0%	99.0% to 99.99%
Target Integrity Risk	10-3 per hour	10-7 per hour
Horizontal Alarm Limit	< 3 m	< 40 cm
Vertical Alarm Limit	-	< 80 cm
Start of the service	2027	2030
Constellations and frequencies	GPS (L1-L2) + Galileo (E1-E5a)	GPS (L1-L2-L5) + Galileo (E1-E5a-E5b)
Tentative System Technology	Real Time ODTS providing Orbits, Clocks and Phase biases and ionospheric data. Integrity alerts	
Tentative User Technology	PPP-Integer Ambiguity Resolution + Atmospheric Information	PPP-Integer Ambiguity Resolution (3 frequencies)+Atmospheric Information
Dissemination Channel	Terrestrial link (EDAS) EGNOS E5b– 500bps FEC ½ (250bps)	
Liabilities	EGNOS HA service provider is responsible of the service when used under the following conditions: ▪ The service in open sky conditions and with at least 8 augmented and monitored satellites being tracked. ▪ Receiver and user-algorithm certified by the relevant competent authority. ▪ The service in "In Operation" mode. ▪ The service with the required authorisation/access control. ▪ No Force Majeure event occurs. The Service provider disclaims any responsibility and liability derived from the use of the service when the previous conditions are not met. Liabilities are assumed by the EGNOS-HA service provider for a given user algorithm and assuming the proper reception and usage of the HA and Integrity data.	
Service Provider	▪ Experienced HA Service Provider shared with Galileo HAS	
Commercialisation scheme	For Free	
Note that the feasibility of the integrity requirements will have to be assessed in a future step as part of the proposed activities in the EGNOSHA service roadmap.		

- **Implementation Roadmap:** The implementation roadmap defines the activities required to confirm the feasibility, consolidate the design and carry out the development and deployment of the EGNOS HA service. The main elements of the implementation roadmap are as follows:

- The duration of the entire EGNOS HA implementation roadmap, from the initial feasibility study to the entry into service of the Full Operational Capability (FOC) is 12 years (January 2018 - January 2030).
- The roadmap covers the service definition, standardisation, system implementation, deployment and provision. The work is organised in five phases:
  - Service Study (2018-2019) aiming at defining the service and perform a preliminary assessment of the feasibility. This activity concludes with the service concept definition.
  - Service Feasibility, Standardisation and Requirements Definition (2019-2022). This phase shall confirm the feasibility of the service (safety analysis), consolidate the standardisation for the service provision side, and contribute to the standardisation of the user solution. The final outcome of the phase shall be the detailed requirements for the service and system needed to launch the detailed design.
  - Service and System Design Phase (2022-2024). The outcome of this phase is the final design of the system and service to be implemented. During this period the standardisation activities for the user side shall be consolidated, hence it is expected to have a common understanding for High Accuracy plus Integrity solutions in the targeted sectors and applications.
  - IOC implementation, Qualification and Service Declaration (2025-2027). This phase focuses on the implementation, qualification and entry into operation of the first EGNOS HA service.
  - FOC implementation, Qualification and Service Declaration. This phase focuses on the implementation, qualification and entry into operation of the EGNOS HA FOC service.

  During these phases a set of Key Decision Milestones shall be carried out aiming to consolidate the outcomes of one phase, evaluate the status and confirm the GO/NO-GO for the next phase.

  In parallel with these activities, there are some tasks which are executed in parallel of the aforementioned ones such as fostering the receiver standardisation, service adoption, R&D related activities for future evolutions, etc.

- **Risk Analysis:** A risk analysis has been performed to identify the potential issues that could take place along the roadmap. Each risk has been evaluated and categorised by its correspondent criticality being the most relevant ones:
  - The feasibility of all the requirements proposed for the FOC service. This risk shall be solved during the service feasibility analysis in the early stages of the roadmap. The outcome of this analysis shall confirm that the requirements can be fulfilled or define the maximum achievable requirements. This information is relevant for the GO/NO-GO decision.
  - Currently, the integrity concept applied in several of the targeted sectors is different and different standards (e.g.: ISO26262) exist in each sector; thus it may take years to reach a common understanding on integrity and to introduce it in the existing standards.
  - The availability of the required infrastructure to provide the EGNOS HA service has a major impact on the achievable performance. Hence, the readiness of the required sensor stations shall be carefully monitored.
- **CBA results** show that EGNOS HA could bring medium/high economic benefits to the majority of the domains and a wide adoption is expected, if the service will be provided for free. Stakeholders see a potential added value provided by EGNOS HA service to almost all domains and applications. In particular, experts consider target integrity, daily availability, position accuracy and convergence time the most interesting EGNOS HA user performances.

  From the users' inputs, it is clear that different considerations drive the CBAs for the selected applications, especially regarding the cost of the equipment for end-users and the initial investments for service providers that can strongly vary and impact the final results of the CBA. Fostering the development of "EGNOS HA-ready" user equipment at affordable price will be a key driver to maximise the service adoption.

- **Open points:** Finally, a set of key open points for next phases of the project have been identified. The main ones are listed below:
  - The targeted integrity level and associated alarm limit for FOC cannot be met using the state of the art technology but could be achievable in the future. Hybridisation of different systems and sensors is a possible solution to explore to reach the most demanding integrity requirements.
  - Specific standardisation activities at service and user level are needed to solve relevant open points: lack of harmonisation among standards, lack of certifying bodies on targeted sectors, unclear split of liabilities between the service provider (committed performance) and the user (standardised receiver).
  - HAPS (High Altitude Platform Station) technology, proposed as an additional dissemination mean to improve service performance could be explored in future studies since such technology is considered still not mature for the 2030+ timeframe.
  - Further discussions with key stakeholders should be carried out in order to understand the potential impact of EGNOS HA FOC service on the market.

3. HIGH ACCURACY USER NEEDS (2025+)

The identification of the user needs for the 2025-2035 timeframe was one of the key tasks of the project. The service definition concept and the service requirements were derived from the identified user needs.

The process to consolidate the system requirements was organised as follows:

- Critically analyse the available documentation from the Galileo Commercial Service studies [RD.7][RD.8][RD.9], the User consultation platform [RD.11][RD.12][RD.13][RD.14] and past projects [RD.10].
- Carry out a consultation involving external stakeholders from targeted sectors: 169 GNSS stakeholders were contacted and 53 of them provided valuable answers. The result of the survey was a set of user needs per sector and application in the form of positioning requirements (i.e. accuracy, convergence time or service availability) and integrity requirements (i.e. Target Integrity Risk, Protection Level or Optimal Performance Availability) for the timeframe 2025+. Inconsistencies between inputs were reviewed in dedicated interviews with relevant stakeholders to consolidate the results.
- Perform a competitive analysis of the different market sectors (Road, Rail, Maritime and Inland Waterways, UAVs, Agriculture, LBS, Surveying and Timing) including the identification of service strengths, weaknesses, opportunities and threats (SWOT). GO/NO-GO criteria for the adoption of the service in the targeted sectors were identified with the contribution of the stakeholders and experts.
- Validate the consolidated user needs with GNSS stakeholders. The consortium organised a teleconference involving 25 experts and users who confirmed the applications' needs for the 2025+ period.

The most relevant results from the user consultation process are summarised:

- **High integrity with high accuracy** (<1m) is a key driver for safety critical applications such as autonomous driving, autonomous vessels and automatic train operations.
- The most demanding accuracy requirements are demanded by automatic steering in the agriculture sector and construction surveying and geodesy in the surveying sector. These applications request accuracy performances below five centimetres.

Automotive applications requires almost instant service readiness i.e. a very fast convergence time (few seconds). The prioritised user applications and requirements requested by the users are detailed in Table 3-1.

Table 3-1: Summary of prioritized applications

Market Segment	Application	Accuracy requirement (Horizontal), 95%	Accuracy requirement (Vertical), 95%	Convergence time	Alarm limit (H)	Alarm limit (V)	Targeted Integrity risk [per hour]	Continuity risk [per hour]	Time to alert	Availability (daily)	Market attractiveness
Surveying & Mapping	Construction – Machine Control	< 5cm	< 5cm	<30 sec	10 cm	10 cm	10E-5	10E-3	10 sec	99.90%	High: (c. 2000 EUR m in 2025)
Agriculture	Automatic steering	2.5 cm	N/A	<30 sec	20 cm	N/A	10E-3	10E-2	10 sec	99.90%	High (c. 1200 EUR m in 2025)
Agriculture	Farm Machinery Guidance	10 cm	N/A	<30 sec	20 cm	N/A	10E-3	10E-2	10 sec	99.00%	Medium (c. 500 EUR m in 2025)

Market Segment	Application	Accuracy requirement (Horizontal), 95%	Accuracy requirement (Vertical), 95%	Convergence time	Alarm limit (H)	Alarm limit (V)	Targeted Integrity risk [per hour]	Continuity risk [per hour]	Time to alert	Availability (daily)	Market attractiveness
Agriculture	VRA-Low	10 cm	N/A	<30 sec	20 cm	N/A	10E-3	10E-2	10 sec	99.00%	Medium (c. 450 EUR m in 2025)
Agriculture	VRA-High	2.5 cm	N/A	<30 sec	20 cm	N/A	10E-3	10E-2	10 sec	99.00%	Medium (c. 450 EUR m in 2025)
LBS	LBS applications for smart utilities	10 cm	N/A	<30 sec	70 – 120 cm	N/A	10E-5	10E-3	10 sec	99.00%	High (2.8 EUR Billion in 2025)*
Road	Automated driving	10 - 35 cm	N/A	<30 sec	25 cm	N/A	10E-7	10E-5	10 sec	99.90%	High (488.17 EUR Billion in 2026*
Rail	Automatic Train Operations	70 cm	N/A	< 1 min	175 cm	N/A	10E-7	10E-5	10 sec	99.90%	Low (all the signalling and train control applications are due to value 100 EUR m in 2025)
Maritime	Port operations - automated docking	10 cm	N/A	< 5 min	25 cm	N/A	10E-5	10E-4	10 sec	99.90%	Medium (c. 150 EUR m in 2025)
Maritime	Autonomous vessels	10 cm	N/A	< 5 min	25 cm	N/A	10E-7	10E-5	10 sec	99.90%	High (136.17 EUR Billion in 2023*
Maritime	Bridge collision-avoidance (Inland Waterways)	20 cm	10 cm	< 5 min	50 cm	25 cm	10E-7	10E-5	10 sec	99.90%	Low (c. 70 EUR m in 2025)
UAV	Goods delivery	N/A	10 cm	< 5 min	N/A	25 cm	10E-5	10E-3	10 sec	99.90%	High (25.52 EUR Billion in 2027)*

In order to define the most relevant features of the potential EGNOS high accuracy service, the study focused on the identification of the most demanding user needs and applications in the timeframe 2025+ that could drive the EGNOSHA service concept design and the service provision scheme. The resulting EGNOSHA target service requirements are as follows:

Table 3-2: EGNOS HA target service requirements

Features	Value	Applications covered
Positioning Accuracy (95%)	5 cm in Horizontal and 10 cm in Vertical component	**Agriculture** (Automatic steering, VRA High and Low, Farm Machinery Guidance, cropping, harvesting) **Road** (Autonomous driving) **Surveying** (Cadastral surveying, construction, mapping, mining, infrastructure monitoring and marine surveying) **Maritime and IWW** (minesweeper, harbour navigation, docking, bridge height alarm, inland waterways applications, port operations and autonomous vessels) **Rail** (Automatic Train operations) **LBS** (Augmented reality, smart utilities, automotive, Payment critical and urban environment LBS applications) **UAVs** (goods delivery, observation, monitoring and Leisure) **Timing** (Financial, PTP, 5G phase/time synchronisation for backhaul and Scientific)
Convergence Time	30 seconds	
Daily Availability	> 99.9%	
Target Integrity Risk	10-7 per hour	
Protection Level	40 cm in Horizontal 80 cm in Vertical	
Service Time to Alert	10 s	
User Time to Alert	< 1 s	
Optimal Performance Availability (daily)	> 99.9%	
Clock Estimation Accuracy (95%)	< 1 ns	
Clock Standard Deviation	< 0.05 ns	
Clock Allan Deviation (Averaging time 105 s)	< 10-15	

Some of the service requirements, derived from the user needs provided by the stakeholders' inputs are challenging to achieve considering the current state of the art. Even if some applications require 2.5 cm Horizontal accuracy, the consortium decided to limit the service performance to 5 cm and focus more on the integrity requirements, considering that integrity is the main differentiator of EGNOSHA compared to other existing high accuracy services. Even if some applications request a horizontal protection level of 10cm, the consortium decided to limit the protection level to 40cm, which will already be very challenging to meet in 10 years' time. For what concerns the time to alert (TTA), the targeted applications would need to detect anomalies in 1 second or less (e.g. autonomous driving, UAVs, etc) at user terminal level. In order to achieve this TTA, the responsibility shall be shared between the user algorithm and the service side. With this approach, the user algorithm shall be responsible of the short term reaction of the safety mechanism whilst the service side shall provide information at a lower rate to contribute the overall integrity of the system. Additionally, the existence of independent sensors available on the user side (IMU, radar, odometer, wheel sensors, LIDAR, cameras, etc) could positively contribute to this TTA as well as targeting different TIRs or Alarm Limits.

4. EGNOS HA SERVICE CONCEPT

The EGNOS HA service concept is the basis for the Service Provider commitment and describes the service characteristics and conditions of use towards the end users. This section presents the EGNOS HA system architecture, its service area, the dissemination means, the service availability and its achievable performance in specific user conditions. Additionally the service liabilities are defined.

The most-critical elements of the EGNOS HA service are listed below:

- Service levels and service area: The service area, the fast-convergence time, the accuracy and integrity requirements impose challenging requirements to the processing facility, to the corrections and alarms to broadcast and to the network of sensor stations.
  - Sensor stations network: the input GNSS data used for the processing of the corrections and alarms are provided by a network of sensor stations. The network of stations has been defined and characterised to provide a minimum service coverage and to ensure the service level provision in the target area.
  - Processing facility: it is the core element in charge of processing the GNSS data received from the sensor stations and generating the High Accuracy information such as orbit and clock corrections, biases, atmosphere information, integrity information or alert messages.
- Dissemination means: they are the channels in charge of distributing the HA data from the processing facilities to the end users.
- Service commitment and liabilities: the Service Provider commits to provide a certain level of performances to users. For safety and integrity related applications, the service provider may be liable in case of service malfunctioning whenever material or life damages occur. Users, on the other hand, are responsible for the use or misuse of the EGNOSHA service at receiver level.

4.1. SERVICE REQUIREMENTS

The service requirements have been driven by the following three points:

- The user needs (Table 3-1).
- The capabilities of the service infrastructure, both at space and ground level, are instrumental in order to define and evaluate suitable service provision solutions.
- The achievable performance with the technology foreseen to be available in the 2025-2035 timeframe.

4.1.1. SERVICE LEVELS

Two service levels were defined: an initial service, mainly relying on the EGNOS V3 network of sensor stations, able to provide sub-meter accuracy performance and a preliminary target integrity level and, in a second step, a full operational service able to meet very demanding requirements in terms of accuracy, integrity, convergence level, etc.

Table 4-1: Service Level

User Performance	Initial EGNOS HA Service (IOC)	Full Operational EGNOS HA Service (FOC)
Positioning Accuracy	<30 cm (horizontal 95%) <50 cm (vertical 95%)	< 5cm (horizontal 95%) < 10 cm (vertical 95%)
Convergence Time	< 20 min (95%)	< 2 min (95%)
Daily Availability	> 97.5%	> 99.9%
Daily Continuity	95.0% to 99.0%	99.0% to 99.99%
Target Integrity Risk	10-3 per hour (*)	10-7 per hour (*)
Horizontal Alarm Limit	< 3 metres (*)	< 40 centimetres (*)
Vertical Alarm Limit	-	< 80 centimetres (*)

User Performance	Initial EGNOS HA Service (IOC)	Full Operational EGNOS HA Service (FOC)
Start of the service	2027	2030
Constellations and frequencies	GPS (L1-L2) + Galileo (E1-E5a)	GPS (L1-L2-L5) + Galileo (E1-E5a-E5b)
Tentative System Technology	Real Time ODTS providing Orbits, Clocks and Code/Phase biases and ionospheric data. Integrity alerts	Real Time ODTS providing Orbits, Clocks and Code/Phase biases and ionospheric data. Integrity alerts
Tentative User Technology	PPP-Integer Ambiguity Resolution + Atmospheric Information	PPP-Integer Ambiguity Resolution (3 frequencies)+Atmospheric Information
Dissemination Channel	Terrestrial link (EDAS) EGNOS E5b (BPSK modulation and data rate of 250 bps1)	

(*) For integrity, a safety case has to be elaborated to refine the Target Integrity Risk (TIR) and Alarm Limit based on the range of applicable errors and failures modes for the proposed service and user solution. Indeed, the imposed requirements of Integrity (TIR & PLs) are considered quite challenging to achieve. Future fault analyses should aim to estimate the residual errors and how to over-bound them.

The full operational service targets accuracy and convergence performance which are beyond the state of the art in 2019 for PPP solutions[2]. Nonetheless, the feasibility analysis carried out in this study shows that by using a mix of PPP-RTK techniques it would be possible to achieve accuracies of few centimetres. In addition, the provision of ionospheric corrections and the provision of corrections for three frequencies are the main contributors to reach a very fast convergence time.

The consortium made some preliminary analyses which show accuracy and convergence time performance close to the target ones.

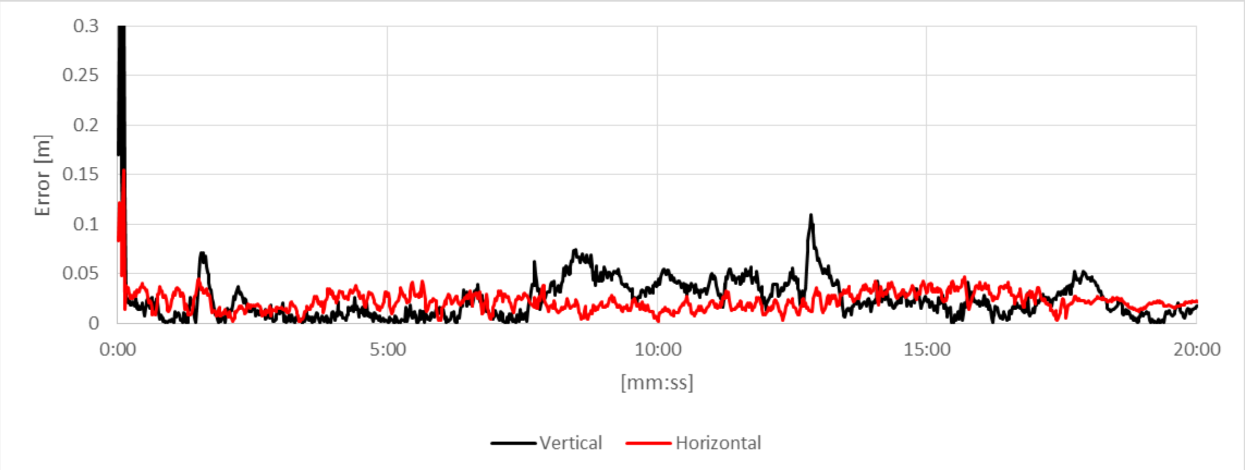

Figure 4-1: Reference PPP+IAR+IONO (dual frequency and dual constellation) with the global and regional network.

For what concerns the integrity performances, the preliminary analyses show that the target performances cannot be reached using state-of-the-art technologies and therefore further studies shall be carried out to assess what level of performance could be achieved considering the technological progress in 2030.

[1] 500 sps with Forward Error Correction ½.
[2] Current RTK solutions can achieve accuracies in the order of 5 cm with almost instantaneous convergence time.

4.1.2. SERVICE AREA

The targeted service area is the European region, more concretely the European Union (EU28). The service area is a driver for the sensor stations network definition. In particular, for the provision of a High Accuracy service with the proposed service levels two subnetworks are needed:

- Global network: a sparse sensor network providing worldwide coverage ensuring a minimum visibility of 4 stations for a satellite in any potential point in the orbit. The processing of this network data allows to calculate the accurate satellite orbit and clock and biases estimation for each satellite to be augmented, as well as integrity parameters associated to these information. The proposed coverage configuration is typically achieved with 40-45 stations sparsely distributed worldwide.
- Regional network: a dense network of stations in the service area required to achieve the fast convergence time. The required density is similar to the one achieved with the EGNOS V3 RIMS considering a few extra stations to cover certain zones at the edge of the service area (see Figure 4-4).

Note that stations can be part of both the global and regional station network. The following figure shows an example of the proposed network. It considers the addition of 22 worldwide stations on top of a regional network (consisting of EGNOS V3 RIMS plus 4 extra stations), obtaining a total of 70 stations.

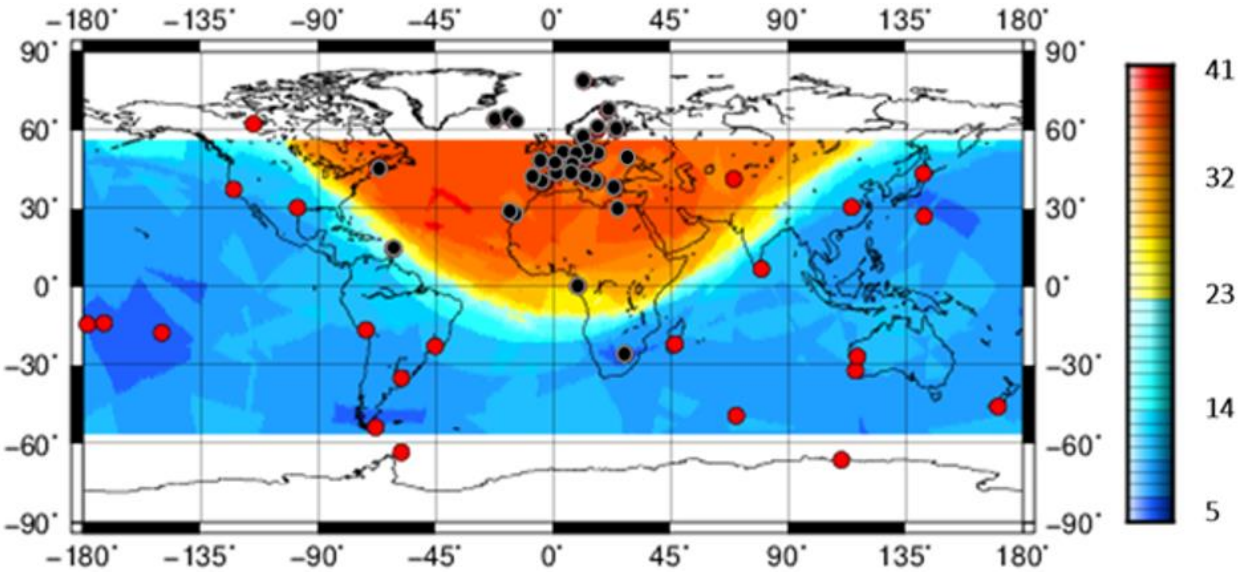

Figure 4-2: Regional Network (black dots: 44 RIMS V3 + 4 extra stations) + 22 stations Global Network (red dots)

(*) Note that the figure shows the projection of the satellite position on the earth surface hence the maximum latitude is limited by the inclination of the satellites.

(**) Note that the colour shows the number of sensor stations tracking a satellite at any possible position of the orbit. Legend is relative to the range represented but colours selected for minimum and maximum are fixed.

The following figure represents the current EGNOS GEO satellites (PRN 123 and 136) footprints and the targeted coverage area (black rectangle). EGNOSHA service would be provided via GEO satellites which have a similar coverage that the one in the figure. The target EGNOSHA service area is the black box labelled EU28 in the figure below.

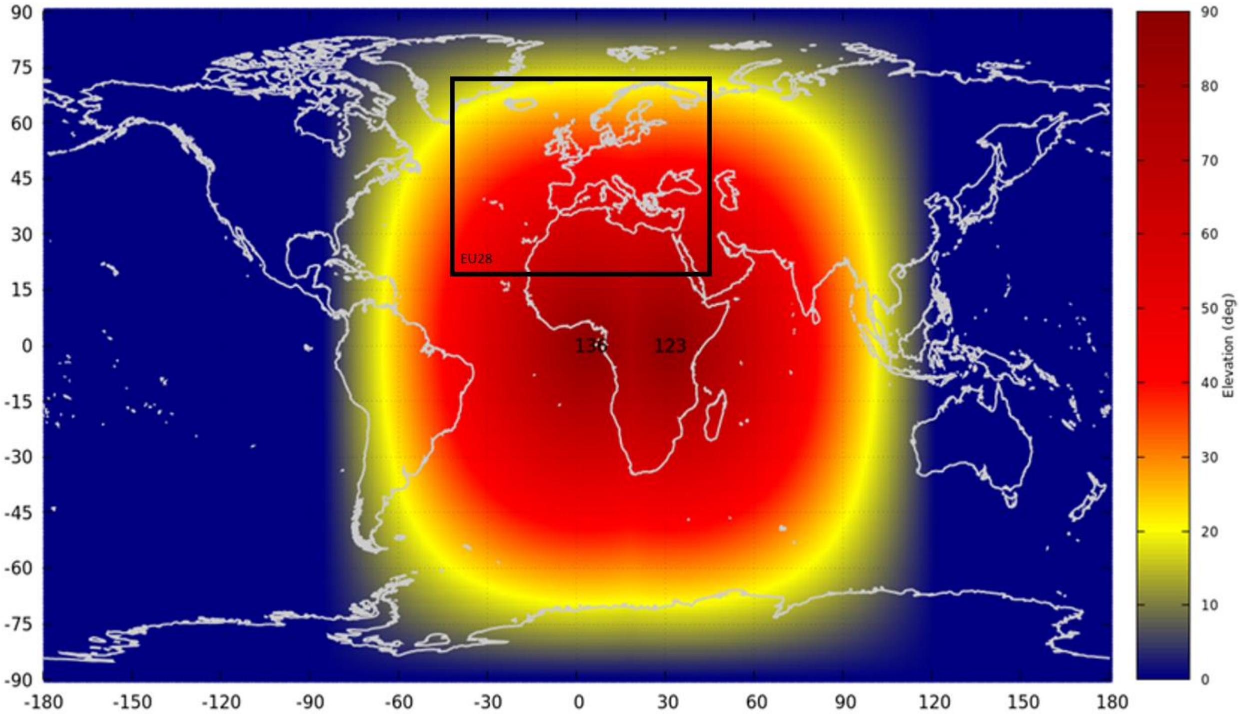

Figure 4-3: Targeted Service Area coverage

Figure 4-4 focuses on the countries that have to be covered by the EGNOS HA service, which are highlighted in green, and on the distribution of the ground stations of the regional network. In addition, it is shown in a clearer way how the coverage area is included in the EGNOS GEO footprints.

Note that the stations labelled in red are the new four stations expected to be deployed for EGNOS V3, (their codename was not defined at the date of writing the present document).

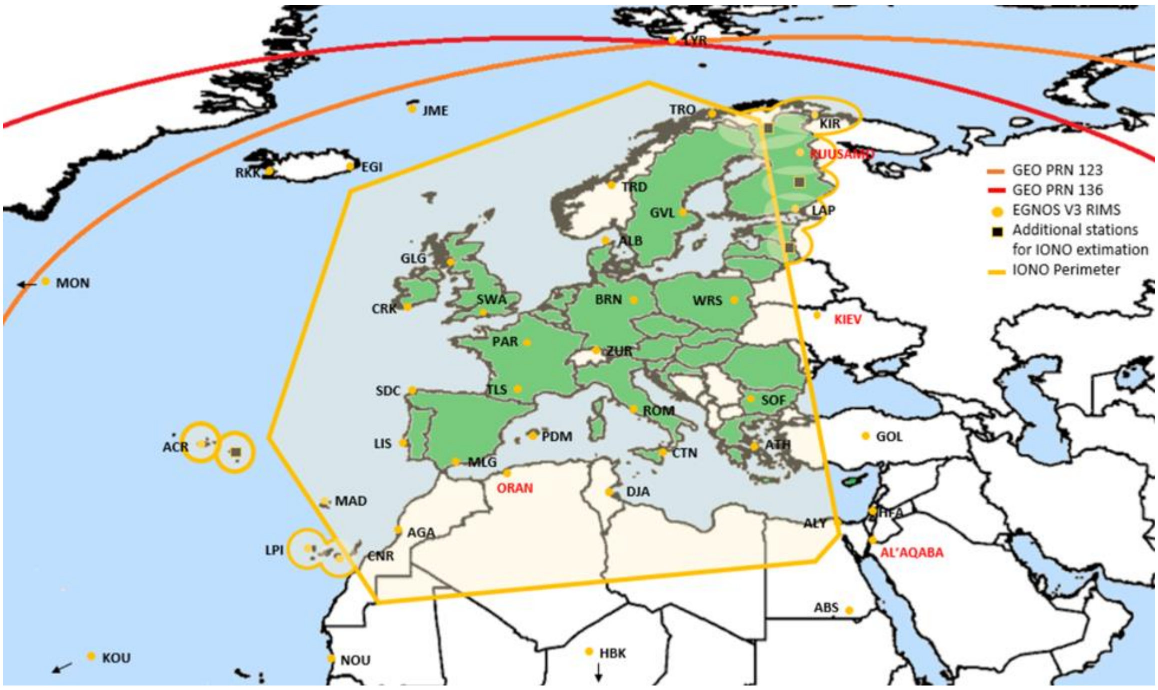

Figure 4-4: Regional Network (V3 RIMS + 4 extra stations)

The area highlighted in yellow represents the effective service area. In order to meet the EGNOSHA required accuracies, the quality of the generated atmospheric data imposes to restrict the service area to the zone covered by the network of sensor stations reduced by 500-600 km in the direction perpendicular to the perimeter defined by the convex hull enclosing the network of stations. Therefore, four extra stations (shown as black squares in Figure 4-4) must be added to cover parts of the EU countries (Eastern part of Finland and Baltic Countries and Canary and Azores Islands) which are outside the yellow perimeter. In these regions, the additional stations will broadcast atmospheric data which allow to meet the target accuracy performance in an area within ~200 km range from the given stations' location. For what concerns Cyprus, the presence of several sensor stations in the surrounding countries with a distance in the range of 400-500 kms is considered sufficient to perform the ionospheric estimation. Note that areas covered by northern stations are elliptical due to the map conversion from spherical to plane.

4.2. HIGH ACCURACY PROCESSING FACILITY

The HA Processing Facility is the element in charge of the generation of the augmentation information. It comprises several key modules:

- HA Processor - Orbit Determination and Time synchronisation module (ODTS): This module processes the observables coming from the global station network to estimate the satellite orbits, clocks and code/phase biases. The error of the estimated orbit and clock shall be in the order of 2-3 centimetre whilst phase biases accuracy shall be in the millimetre level.
- HA Processor - Atmosphere data estimation: A proper estimation of the ionosphere is needed to achieve fast convergence. An accurate ionosphere estimation eases the ambiguities resolution process in the user level algorithm. In this sense, an ionosphere estimation with an accuracy below the TECU[3] level is required for the final service provision.
- Safety processor: Both ODTS and Atmosphere data generator shall be able to generate the integrity related data required to monitor and protect from the hazards and failure events affecting them. An integrity alert generator shall perform the safety validation to raise alerts when needed.

Other elements as the input data check and encoders are common to the three modules. A candidate architecture is depicted below:

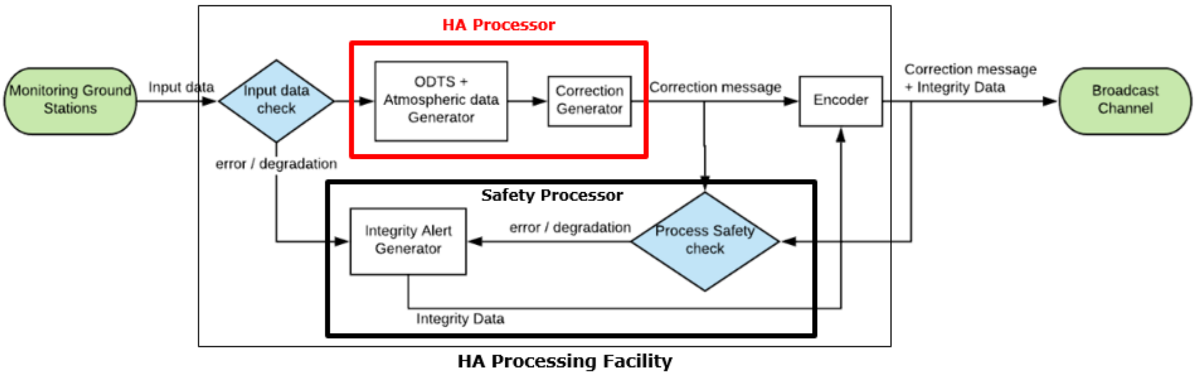

Figure 4-5: EGNOS HA Service Processing Facility architecture

4.3. DISSEMINATION MEANS

The EGNOS HA dissemination means are the elements in charge of distributing the HA data to the end-users. The definition of the dissemination means started with an analysis of the different options (i.e. GEO broadcast via E5a or E5b, Terrestrial links, HAPS, VDES, space links), and concluded selecting the most appropriate options to implement the EGNOS HA service.

[3] Total electron content (TEC) measures the total number of electrons integrated between two points, along a tube of one meter squared cross section. It is often reported in multiples of the so-called TEC unit, defined as *TECU* = 10^{16} *el/m*^{2}. Typically, ***1 TECU implies a delay of 16 centimetres*** of delay in the L1/E1 signals.

- EGNOS E5b: the E5b channel currently available in a subset of the EGNOS GEOs is proposed as the baseline for the HA data transmission due to the independence with other EGNOS services and the available bandwidth. It has to be considered that the E5b, E5a and E1 frequencies are included in the allocated spectrum for Aeronautical Radio Navigation Services (ARNS, 960-1215 MHz) employed by Civil-Aviation users and allowing the provision of data dedicated to safety-critical applications (E.g.: SoL). Therefore, the SoL services shall not be impacted by new services provided in such bands. This means that E5b frequency shall follow several technical requirements (RTCA-DO 292) in order to be properly used for the EGNOS HA service. The proposed band characteristics foresee a BPSK modulation and Data rate of 250 bps (500 sps with Forward Error Correction ½).

  A second option is to change the modulation of the E5b, which may allow to reach higher bandwidth. Nevertheless, a higher bandwidth implies spreading energy in the frequencies and thus the complexity to successfully acquire and maintain the track of the signals increases.

- Internet link: an internet-based transmission compatible with any other channel is proposed in order to complement the satellite dissemination. This link will be highly beneficial for users working in non-open-sky conditions where GEOs may not be visible. Furthermore, internet link does not suffer from bandwidth limitation for the amount of data being broadcast.

The use of other frequencies such as E6 has been assessed as part of the study. In the particular case of the E6, the same modulation used in Galileo has been considered. Its bandwidth is of 500 bps which doubles the option of the E5b. Keeping aside that new transponders are needed in the space segment, the issue with the modulation change aforementioned for E5b is also applicable. Additionally, most of the commercial receivers, including mass-market ones, are compatible with E5a/b frequencies but not E6. However, E6 signal will be implemented to be used for Galileo Commercial Service, so in 2027+ receivers could be already compatible.

A summary of the trade-off between the different dissemination channels options is as follows:

Table 4-2: Dissemination Channel trade-off

Dissemination Channel	Advantages	Drawbacks
GEO broadcast on E5a (using SBAS L5 ICD as is, i.e. without delta-corrections)	Fast adoption due to use of existing standards/receivers (No impact on applicable standards/receivers)	EGNOSHA IOC and FOC performance not achievable Low availability of GEOs at high latitudes or urban areas
GEO broadcast on E5a (using SBAS L5 ICD with delta-corrections)	IOC performance achievable in Europe Potentially simple user algorithm Moderately fast adoption due to use of existing standards/receivers (same SBAS L5 ICD plus delta corrections using spare bits and adding a message with additional corrections)	FOC performance not achievable Standardisation complexity Potential impact on standard DFMC performance Low availability of GEOs at high latitudes or urban areas Need to update Receivers firmware
GEO broadcast on E5a with or without delta-corrections, plus on E5b for dissemination of ionosphere and troposphere corrections, biases…	FOC performance achievable in Europe service area Fall-back to IOC possible if E5b correction are not available Sufficient bandwidth for future features and improvements	Standardisation complexity Potential impact on standard DFMC performance Low availability of GEOS at high latitudes or urban areas Cross dependencies of corrections disseminated on two different channels. Some Rx might not support both E5a and E5b frequencies
GEO broadcast on E5b only	Independent from SBAS SoL service More flexible regarding standardisation IOC and FOC performance achievable Modulation of the signal can be adapted (with different modulation higher bandwidth can be achieved)	Low availability of GEOs at high latitudes or urban areas If different modulation with higher bandwidth, tracking more complex

Dissemination Channel	Advantages	Drawbacks
GEO broadcast on E6	IOC and FOC performance achievable More flexible regarding standardisation Modulation of the signal could be adapted	Low availability of GEOs at high latitudes or urban areas E6 channel not available on EGNOS GEO Need of new compatible receivers
Terrestrial Link (internet based)	No bandwidth limitation IOC and FOC performance achievable Immediate adoption Worldwide coverage Better reception in certain environments (urban areas, high latitudes if connection is available) Compatible with any GEO-based signal	Need of a reliable internet connection Lack of connection in remote areas

The logic scheme of data dissemination elements in the HA delivery chain is depicted hereinafter.

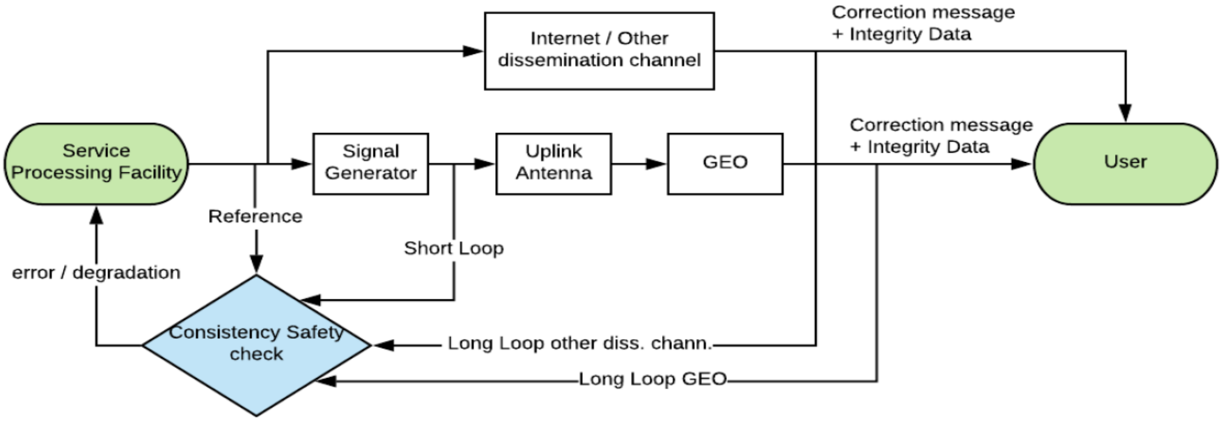

Figure 4-6: EGNOS HA service dissemination means architecture

Independently of the channel used for the High Accuracy message distribution, a dedicated safety check shall confirm the consistency of the message generated, the message broadcast and the information received by the users and sensor stations. These monitoring loops are the short-loop and long-loop consistency checks. Each dissemination mean shall implement dedicated short and long-loop checks.

Based on the presented trade-off, it is concluded that EGNOS E5b with BPSK modulation and Data rate of 500 sps (FEC ½ → 250 bits/sec), and internet based dissemination channels are the most suitable options for both IOC and FOC EGNOS HA service provision.

4.4. RESPONSIBILITIES AND LIABILITIES

The analysis of the service concept allowed to identify the roles and responsibilities of the major actors involved in the EGNOSHA service provision scheme and to define what service liabilities have to be taken into account.

Firstly, the responsibilities of both user and service provider are described. Secondly, service liabilities and the proposed contract liabilities between the service provider and European Commission are identified.

4.4.1.RESPONSIBILITIES OF THE USER

A potential EGNOSHA service user is responsible for the use or misuse of an EGNOSHA-enabled receiver, in particular the following elements shall be covered:

- The antenna and receiver shall be suitable for the EGNOS HA services, i.e. supporting the tracking of E5b and/or the internet link.
- The receiver shall be compliant with the EGNOSHA ICD and the PPP algorithm as defined by the EGNOS HA service.
- The receiver shall be able to process the EGNOSHA data disseminated for High Accuracy and integrity making use of the EGNOSHA service user algorithm.
- The receiver and antenna shall provide a minimum quality in the GNSS measurements (e.g.: pseudorange noise, carrier noise, Doppler noise, cycle slip rate …).
- The receiver and antenna shall be designed and validated for safety purposes. In particular, parameters and functions subject to introduce errors and hazards in the system shall be controlled i.e. characterization of maximum likelihood of failure event/modes.
- The installation of the receiver and antenna shall be done and validated according to the rules and guidelines provided by the EGNOSHA service.
- Redundancy of antenna and receivers shall be considered for certain applications and to maximise availability (e.g.: double antennas to detect spoofing and jamming).
- Hybridisation of EGNOSHA service solution with other techniques can be done by the end-users to achieve a higher level of safety. In this case, the end-user is responsible of constructing its own safety solution, make the appropriate safety case analysis, define the safety-level apportioned by the different elements of the system and control the data merging. EGNOS HA liabilities will be applicable only whether the algorithm proposed is not modified.

4.4.2.RESPONSIBILITIES OF THE EGNOSHA SERVICE PROVIDER

The potential EGNOSHA Service Provider would be in charge of:

- The proper operation of the HA processing facility including:
  - Input data monitoring and checks
  - HA and integrity data generation and monitoring of the output correctness
  - Monitor the proper distribution of the augmentation data thanks to the long and short loop monitoring strategy in the dissemination channels
  - Alerts generation
  - Planned outages notification
  - Ensure the service performance as defined in the Service Level Agreement (SLA) with the user.
- The execution of system operations 24/7
- The maintenance activities, including predictive maintenance.
- Cybersecurity and security related activities.
- Helpdesk and user-interfacing activities (e.g. website maintenance).

Additionally, the potential EGNOSHA Service Provider would need to establish a service level agreement with the EGNOS service provider, who is in charge of the operation of the EGNOS V3 infrastructure, to define the minimum performance level required from the EGNOS V3 infrastructures.

4.4.3.SERVICE LIABILITIES AND COMMITMENT

In case of damages caused by given events, the Service Provider on behalf of the European Union would be the liable in accordance with the Article 340 of Treaty of Functioning of the European Union

(TFEU) and with general principles common to the laws of the Member States. The text of the article is reported here below:

Article 340 (Ex Article 288 TEC) *The contractual liability of the Union shall be governed by the law applicable to the contract in question.* *In the case of non-contractual liability, the Union shall, in accordance with the general principles common to the laws of the Member States, make good any damage caused by its institutions or by its servants in the performance of their duties.* *Notwithstanding the second paragraph, the European Central Bank shall, in accordance with the general principles common to the laws of the Member States, make good any damage caused by it or by its servants in the performance of their duties.* *The personal liability of its servants towards the Union shall be governed by the provisions laid down in their Staff Regulations or in the Conditions of Employment applicable to them.*

In order to fulfil the requirements and service levels stated in the EGNOS HA service definition, the EGNOS HA service provider shall achieve a minimum level of performance and availability in the data disseminated by the service. This minimum performance level of data shall be enough to allow the users to achieve the required accuracy and integrity levels committed by the service.

Next table provides a first definition of the minimum performance needed for the information disseminated by the EGNOS HA service:

Table 4-3: EGNOS HA service disseminated data minimum performance

Disseminated Data	Minimum Performance for IOC	Minimum Performance for IOC
Orbit Accuracy	< 10 cm	< 4 cm
Clock Accuracy	< 0.75 ns	< 0.25 ns
Ionosphere accuracy	< 1 TECU (*)	< 0,7 TECU (*)
Phase bias accuracy	0,04 cycles	0,04 cycles
Integrity Alert	< 10 s	< 10 s
Availability (daily)	> 97,5 % of the time	> 99,9 % of the time
Continuity (daily)	95.0% to 99.0%	99.0% to 99.99%
Correction generation latency	< 7 s	< 7 s

This commitment shall be part of the EGNOS HA Service Definition Document and the required monitoring, reporting and validation means shall be implemented.

4.4.4. LIABILITY DISCLAIMER

The EGNOSHA Service liability disclaimer has been derived from the EGNOS Safety-of-Life Service Definition Document (SDD) since the EGNOSHA service would provide high accuracy with high integrity and most of the target applications (e.g. autonomous vehicles) are safety-relevant. The disclaimer would state as follows:

The EGNOSHA strictly related entities, represented by the European Union (as the owner of EGNOS system), the European GNSS Agency (as the EGNOS programme manager) and the EGNOSHA service provider expressly disclaim all kind of warranties (whether expressed or implied) to any party, except for EGNOS HA service users. It is understood that only the strictly related entities above mentioned can modify, through advices or information, the given liability disclaimer.

On the user side, the European Union and/or the SA and/or the EGNOSHA service provider are not responsible neither liable for any type of indirect, special or consequential damages, including but not limited to, damages for interruption of business, loss of profits, goodwill or other intangible losses,

resulting from the use of, misuse of, or the inability to use the EGNOS High Accuracy Service. In particular, no responsibilities nor liabilities are claimed by EU/GSA/SP if a given damage, error, failure (or its direct consequence) can be related to:

- *Inappropriate use of EGNOS High Accuracy service:*
  - *Use beyond conditions and limitations defined in the EGNOS HA Service Definition document*
  - *Standalone integrity is provided in Open sky condition(*) with at least 8 satellites in Line Of Sight(**)*
  - *Use of modified or non-enabled/non-compliant user algorithm*
- *Inappropriate use of EGNOS High Accuracy equipment:*
  - *Receivers not compliant with EGNOS HA requirements*
  - *Receivers not certified nor approved by the competent authority*
  - *Receivers malfunctioning*
  - *Receivers accessing the service without the required authorisation (if any)*
- *Use of EGNOS High Accuracy service when advices of potential outage of the given service are provided from the EGNOS HA service provider (e.g.: in case of planned maintenance actions) or not working "in-operation" mode status.*
- *Force Majeure events*

(*): The number of satellites is based on the ability of the receiver to perform RAIM or Fault Detection and Exclusion (FDE), which means the ability of detect a potential faulty satellite and exclude it from the process of calculation of the navigation solution. Knowing that a minimum of 4 satellites is needed to calculate the user position and knowing also the satellite fault rates, a normal receiver can: detect a fault with at least 5 visible satellites and exclude it with at least 6. Nonetheless, due to the satellites geometry, more satellites in view could be needed. The value of 8 satellites, either of the same or of different constellations, in LOS is reasonable to ensure continuity in navigation solution with integrity.

(**): The definition of the liabilities associated to the Open Sky may be revisited. An open sky condition is considered as an environment without any kind of object affecting the user solution above 10º, which is the proposed masking angle for the GNSS satellites.

4.5. SERVICE PROVISION ASPECTS

The decision on the HA Service Provider is critical for the implementation and provision of the service. The consortium considered that an experienced High Accuracy Service Provider (HASP) would be the most suitable solution. Pros and cons of such proposal are shown in Table 4-4.

Table 4-4: Experienced HA Service Provider pros and cons

Player	Advantages	Drawbacks
Experienced HA SP	- CAPEX / OPEX Cost saving: - Cost reduced by possibility of RIMS usage. Experienced HASP will have its own available network - Experienced HASP could have its own HA processor. Evolutions for integrity are required - HA experience - Low risk for scheduled implementation roadmap (most of infrastructure already deployed)	- Extra effort for Physical/cyber security (different stations networks) - Low level of control over the service by the EU (property of data, infrastructure, etc.) - Need of SLA to cover such lack of control.

4.6. SERVICE SYNERGIES WITH GALILEO HA SERVICE

The Galileo CS High Accuracy has been re-profiled in early 2018 turning from the original commercial approach to a High Accuracy Service provided for free. An analysis of the main synergies between EGNOS HA and Galileo HA services were performed with the following conclusions:

1) **Integrity:** As resulting from the user consultation, integrity is one of the main requests from the users. Galileo HAS does not include this feature, hence having it in EGNOS HA is a key driver for the adoption and success of the service.

2) **Improved performances:** Galileo HAS will provide a worldwide service in 2020+ with a good level of accuracy (<20 cm). in the timeframe 2025+, EGNOSHA would provide better accuracy performances that Galileo HAS but only over Europe thanks to the availability of a dense network of stations.

3) **Service Area:** the service area and bandwidth is one of the main differentiators between both services. Galileo HAS will provide a worldwide service whilst EGNOSHA service area would be Europe.

4) **Dissemination means:** The baseline dissemination means for EGNOS HA would be the GEO broadcast on E5b and an internet link. Galileo HAS will use MEO satellites broadcasting on E6 and an internet link. The use of different channels for EGNOS and Galileo would bring a good level of diversification which could serve different markets and/or provide good redundancy of High Accuracy services.

5) **Synergies:** the consortium proposes some elements to consider to improve the synergies between Galileo HAS and the potential EGNOSHA service. A common high accuracy correction generator could be shared; nonetheless, having a common high accuracy correction generator may lead to common failures between the two systems.

   In addition, the consortium proposes to share the EGNOS and Galileo GNSS data collected by the sensor stations. The EGNOSHA ground network requires a total of 70 sensor stations to provide EGNOSHA FOC service, which means deploying additional 22 worldwide and 4 regional stations on top of the 44 EGNOS V3 RIMS. On the other hand, if synergies between EGNOS and Galileo could be made, the total number of stations could be composed of 44 EGNOS V3 plus Galileo GSS plus few additional stations (around 10). With this option, less additional stations would be needed to ensure the targeted performances (implying less cost and implementation times reduction) but the interface between the data broadcast on Galileo HAS and EGNOS HA services has to be defined, since the integrity fields are linked to the batch of corrections. In addition, in order to reduce the cost and time to deploy additional stations, other stations like the IGS ones, which cannot be fully controlled by the system, could be used but only for the computation of corrections since the integrity computation function has to rely on fully controlled stations.

4.7. ADDITIONAL REMARKS ON EGNOSHA SERVICE PROVISION

The consortium identified other relevant factors linked to the EGNOSHA service provision concept:

1) **Timeline:** EGNOSHA service would be operational only in 2025+. Nowadays, integrity is not provided by any high accuracy service providers, but the situation may change in a few years and competition might be significant.

2) **Fee charging scheme option:** the feedback from the consulted stakeholders has been to provide the EGNOSHA service for free. However, if a charging scheme to access the EGNOSHA service is finally implemented, three elements should be considered:

   a. The amount of the service fee should be in line with the prices of the other high accuracy services in the market to avoid market disruption.

   b. Provision of integrity would be instrumental to foster adoption.

c. Access control would be required to allow access to subscribed users only.

5. USER SEGMENT

5.1. USER SEGMENT DEFINITION

The last element of the EGNOS HA service delivery chain is the user segment. Once the HA message is sent through one of the given dissemination means, it is acquired by an EGNOS High Accuracy receiver. The receiver first checks the messages' integrity and consistency at safety level and then processes it, providing the correct position with related protection level to the user, through a certified PPP algorithm. The logic scheme is depicted below.

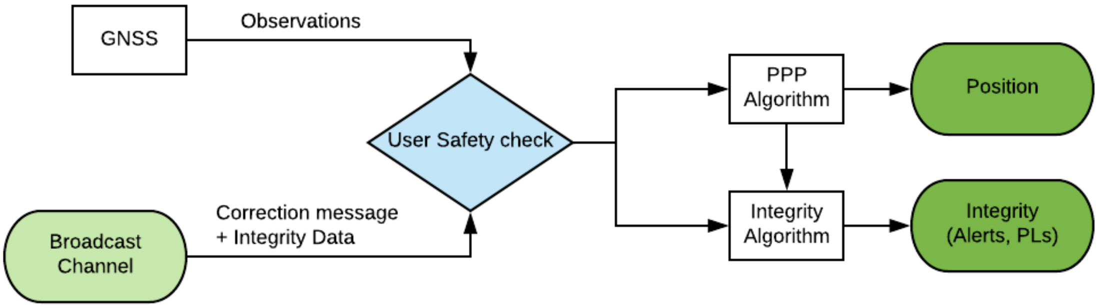

Figure 5-1: EGNOS HA service user segment architecture

The following elements are part of this process:

- Antenna and receiver equipment: both receiver and antenna are critical elements to achieve the most demanding performances and ensure the integrity. In this sense, a validation or certification process of equipment shall be done to ensure the quality and suitability of the GNSS measurements for safety purposes and verify their validity for the EGNOS HA service.
- HA Positioning and integrity algorithm: the EGNOS High Accuracy service main differentiator compared to other High Accuracy services is integrity, which means that the user trustworthiness of the provided position is one of the key goals of the service. For this reason, the definition of a common user algorithm is required, otherwise no control on integrity and associated liabilities can be imposed.

  The intended algorithm shall receive and process the integrity status monitored by the Processing Facility, but also perform specific monitoring of hazards affecting the end users. This is the case of events related to the tracking and performances of the phase measurements.

  Finally, given the different nature of the applications considered in the study, the environmental conditions may have a relevant impact in the end-user performances. In this sense, the algorithm shall be able to deal with quite different multipath effects as well as with the continuous loss of line of sights.

  Hybridisation with other sensors (IMU, 4G, cameras, map-matching…) can be also explored by interested companies (i.e. automotive, agriculture, maritime), who could determine how to apportion GNSS/EGNOS HA solution and how to combine it with other sensors/technologies available at user level. In this case, the end-user is responsible of constructing its own safety solution, make the appropriate safety case analysis, define the safety-level apportioned by the different elements of the system and control the data merging.

5.2. HA STANDARDISATION & CERTIFICATION

Activities of standardisation and certification have been considered at service and user level, as done for integrity definition as well. The service delivery chain is defined from the GNSS data collection to the HA data transmission for the user while, for the user side, those scenarios in which the user could take advantage of such data. This separation is based on the different work needed for the open points of both tasks and solve them.

Along the EGNOSHA project, a first study has been carried out aiming to identify the actual panorama of standards and certification authorities which could be linked to the EGNOS HA service. In summary:

- The most relevant sectors (Automotive, Rail, and Maritime) actually follow already existing standards (e.g. ISO26262 for automotive electronic components or EN50126 for safety life-cycle of rail components). In addition, a standard is being developed for functional safety in autonomous driving, called SOTIF (ISO/PAS 21448). Standardisation and certification are already trending topics in these sectors, thanks also to the raising of certain technical committees (e.g. ISO TC-204 for intelligent transport systems) or the International Maritime Organisation (IMO) which recognises the relevance of new technologies for navigation, issuing guidelines on navigation issues.
- In other sectors such as UAV (public side) or agriculture, no requirements, standards or regulation bodies exist (or at least they are less relevant in terms of safety). UAV sector relies to EASA /SESAR recommendations for public use, and each of EU national authorities has its own set of regulations but none relevant for integrity nor safety.
- High Accuracy is foreseen to be a relevant market in the next years, and several industries/groups /companies are already carrying out studies for HA certification and accreditation. One of the groups is RTCM SC 134 but other private industries act (presently) as authorities certifying its own products because there is no an authority applicable to every sector/application. Beside this, activities carried out by the RTCM SC 134 actually aim to define an HA integrity standard for the most relevant sectors through harmonisation studies of the integrity definition and categories. For integrity at user level, it is planned to study main common safety cases of each sector (looking for common requirements) and then to study of the most safety-critical applications separately. A draft standard for HA integrity standardisation is foreseen to be published at the end of 2019.

The consortium proposes to consider two different paths for service and user standardisation certification. In particular:

- At service level, the harmonisation activity along the applicable standards would focus on the HW and SW processes and tests for validation (e.g.: ISO26262 for automotive or IEC61508 for general electronic components). This is similar to the activities actually carried out by RTCM SC 134. However, a Pan-European certification authority during the oversight for the EGNOSHA high accuracy and high integrity services still does not exist and its creation might be lengthy and complex. The proposed process for service standardisation follows.
  - The EGNOS HA requirements, would be identified through iterative activities based on Functional Safety.
  - If a certain safety Integrity level for a system HW component is required, the related manufacturing process shall guarantee that at its state-of-the-art such requirement is accomplished and it has no defects. Therefore, an alignment with already existing electric/electronic components standards (e.g.: IEC61508) is foreseen, as well as a harmonisation study of the existing standards applied to the targeted sectors and applicable to the EGNOS HA system.
  - At this point, identified the inputs as EGNOS HA system requirements and the applicable standards, the last step would be the service and provider certification. The only open point would be the identification of certification authorities for High Accuracy services in Europe and for each of the targeted sectors. The EC/GSA are highly recommended to address the main certification authorities like IMO for Maritime, or ERA for Rail. Nonetheless, currently no certification entities nor technical norms are present for High Accuracy, but the relevance of HA services, their fast adoption in the last decade and the increasing of the applications in which they are used, recalls the need of certifications, standards, regulation bodies in the near future.

  A logic scheme of the proposed service certification process' activities follows:

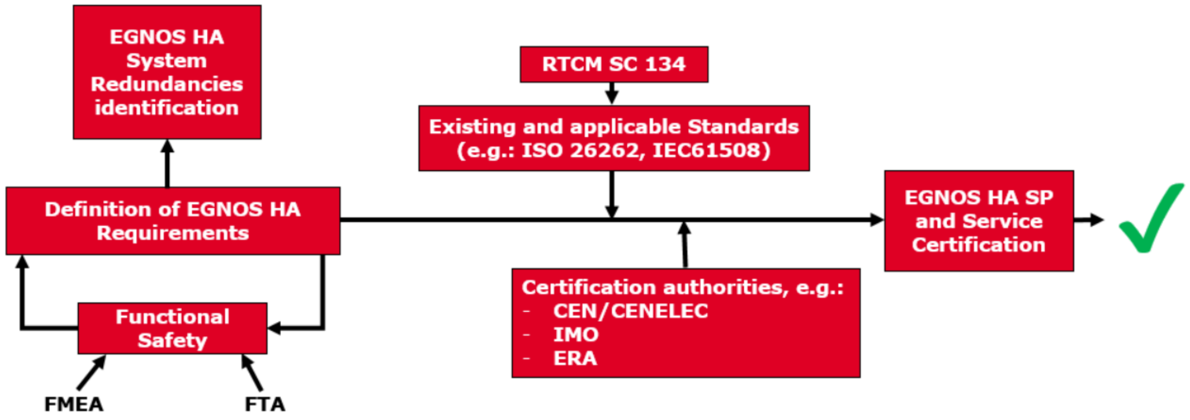

Figure 5-2: Proposed certification process for EGNOS HA at service side

- At user level, the identification of the HA algorithm is the key element. RTCM SC-134 foresees a first study of the common (i.e. not targeting any specific sector) safety cases at user level. Then, a study of safety cases per sector and for the most demanding safety-critical applications would need to define the threats that could affect the user solution (e.g.: multipath, interferences, etc.) and degrade the Protection Levels. Each threat shall be weighted for the PL computation. In addition, the user HA algorithm would need to receive all the alerts generated by an error/failure along the delivery chain, to decode the signal and provide integrity and high accuracy positioning.

  The HA algorithm is an input for the receiver manufacturing, together with the applicable standards and the HA standard describing the manufacturing tests and requirements. Once built, the prototype of EGNOS HA receiver shall be tested with the supervision of certification authorities. The role of the certification authority is to confirm the compliance between the EGNOS HA performance and the applicable standards, including the results of the test campaigns and demonstrations as presented in subsection 4.4.4. The final result would be the certification of EGNOS HA service for the relevant safety-critical applications. A scheme of the activities' plan proposed by the consortium is as follows:

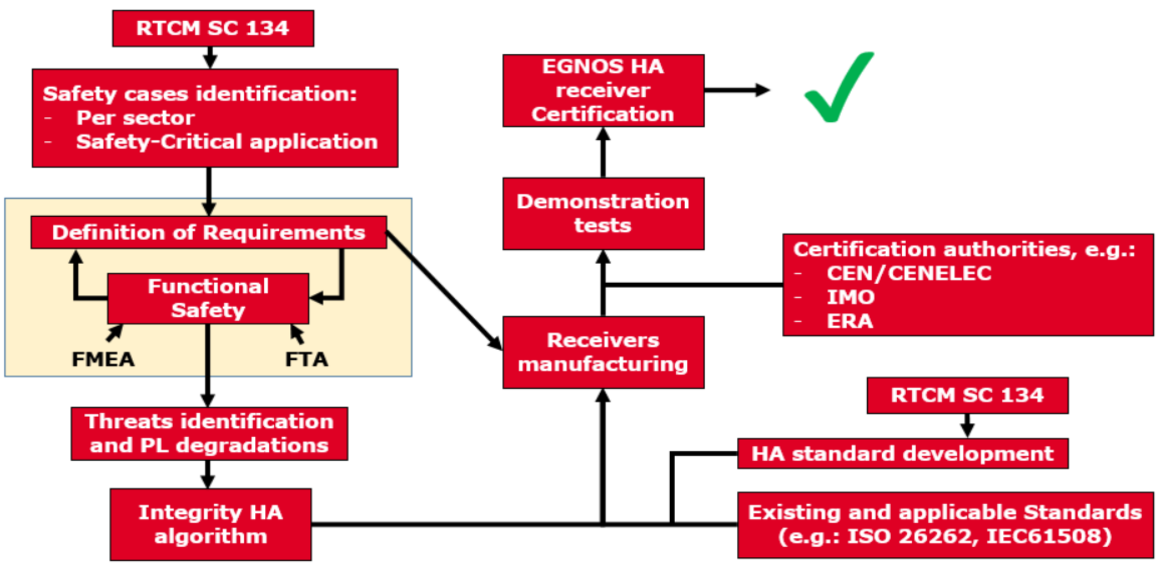

Figure 5-3: Proposed certification process for EGNOS HA at user side

6. SERVICE IMPLEMENTATION ROADMAP

This section proposes a service implementation plan, which describes the phases that would be needed to achieve the Full Operational Capability (FOC) of the potential EGNOS HA service. The implementation roadmap is defined both at service and system engineering levels, and includes standardization/certification activities, system development processes and R&D activities.

6.1. IMPLEMENTATION PLAN

The present implementation roadmap considers external dependencies for certain activities (i.e.: EGNOS V3 infrastructure ready by 2025) or potential interdependencies with other activities internal to the EGNOS HA roadmap itself. Some of these links may impact the proposed schedule and for this reason they have been considered and are presented under the analyses of the critical path and EGNOS HA risks.

The logic behind the implementation roadmap follows the division of tasks into service and system engineering and a classification per targeted Service Level. The entire roadmap is divided into phases; each phase is divided into tasks, which consequently are divided into activities. Nonetheless, this classification is not very stringent, since some activities and tasks are planned to be performed continuously through different phases, or in parallel with other tasks. This have been done since, despite of the tasks' classification and division, the first objective of this implementation roadmap remains the optimisation of the activities' allocation in terms of time, effectiveness and efficiency, and the identification of the critical path and major risks.

The duration of each phase has been estimated once having analysed the list of activities identified and their scope. These activities are presented in detail in the following pages, specifying the stakeholders involved, the type and scope of the activity, what and how has to be performed and what the expected outcome is.

The activity workflow is presented showing both activities depending on the SL and on the service/system engineering. In order to complement the information shown on Figure 6-1, a table detailing the activities is also provided. Three main actors were identified:

- The European Union is the owner of EGNOS and Galileo system and would be the owner of EGNOS HA system and of the property rights of their related reports and documentation.
- The EGNOS HA Service Provider, as the industry (or consortium) in charge of all the activities related to the service provision.
- Industry (or consortium) tasked to build the system and perform specific analysis related to the EGNOS HA Service Provider

The implementation roadmap has seven Key Decision Milestones (KDM highlighted in red, Figure 6-1), which correspond to decision points for the Programme before moving to the next phase of the road map. Indeed, each decision point is fed by the outcomes of the previous phases; At every key decision milestone:

- In case of a decision to GO, the EGNOS HA implementation process would follow the proposed plan, going to the next phase.
- In case of a NO GO decision, the activities would be reworked in order to reach the expected outcomes and achieve the GO status or it could be decided to stop the project (due to the unfeasibility of the service, lack of interest from the users or other reasons). In case of a NO GO decision, the road map could shift; therefore, the progress of the activities needs to be closely supervised in order to perform an early detection of problems and the execution of the required corrective actions

The implementation roadmap figure and table are provided as follows.

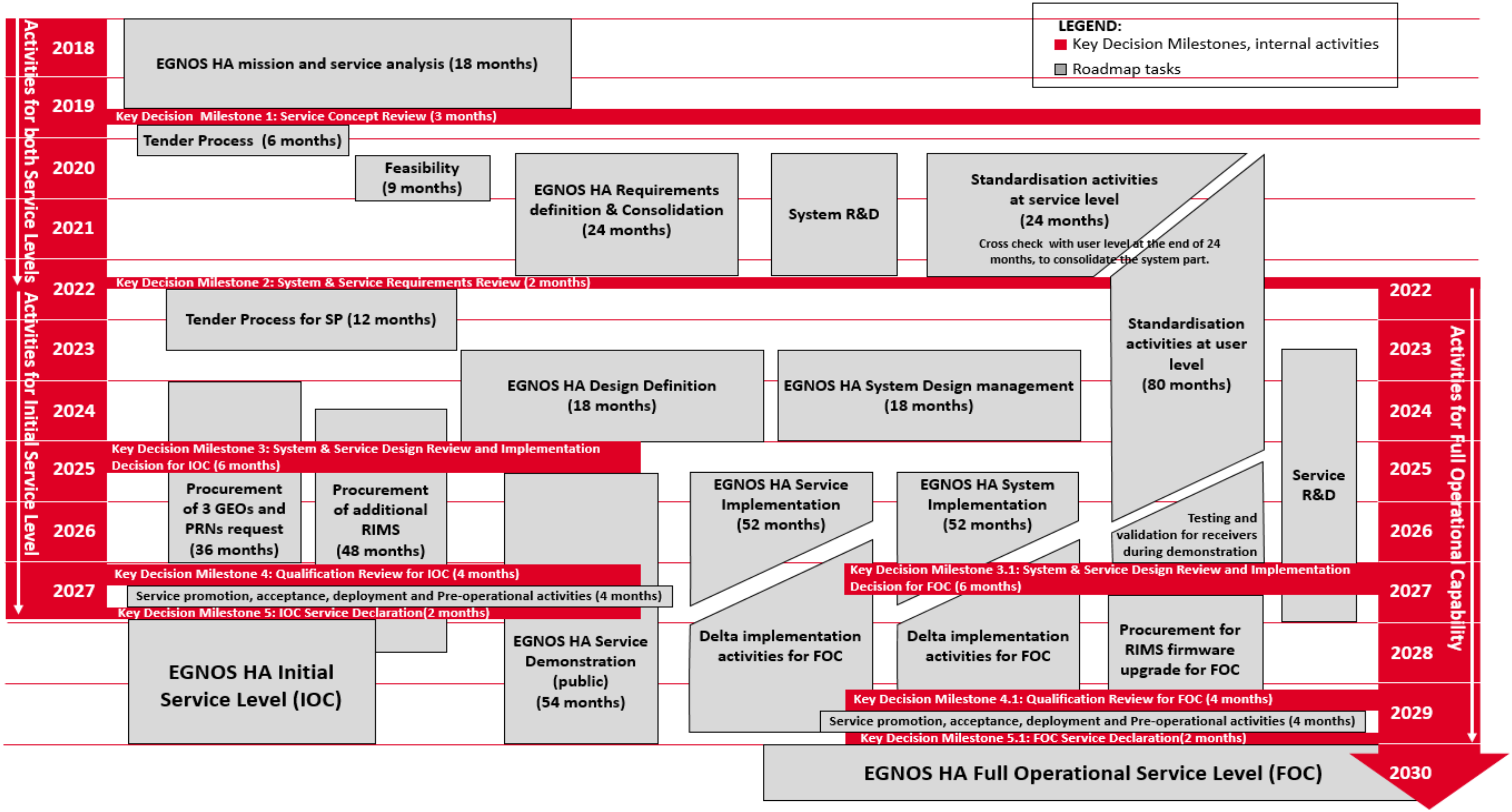

Figure 6-1: EGNOS High Accuracy service proposed Roadmap overview

Five main phases (Mission and Service Analysis, Requirements Definition & Consolidation, Design Definition, Implementation & Demonstration, and Operations) are proposed. From the KDM 2 onwards, the other KDMs are split depending on the targeted SL. The duration of each key decision milestone is proposed based on the type of the performed task, its outcomes and the criticality of such decisions.

- Key Decision Milestone 1: Internal decision of EGNOS HA service concept analyses.

  With a duration of 3 months, from August 2019 to October 2019, the Programme would analyse the outcomes of the mission and service analysis. This internal activity aims to assess the technical and economic feasibility, identify potential uncertainties of technical aspects and the related criticalities which could affect the correct implementation roadmap. Additionally, a consolidation of the required activities would be performed through internal considerations (e.g.: dependencies with EGNOS V3 schedule). The outcome of this activity is a critical point, because it defines if the EGNOS HA service concept shall continue or stop.

- Key Decision Milestone 2: System & Service Requirements Review

  With a duration of 2 months, from May 2022 to June 2022, the Programme would analyse the outcomes of Requirements Definition & documentation consolidation. The activity is focused on confirming and validating the proposed requirements, giving the GO status for the viability of the service. This outcome will be one of the most relevant inputs for the Tender Procurement Process.

- Key Decision Milestone 3: System & Service Design Review and Implementation Decision for IOC

  With a duration of 6 months, from January 2025 to June 2025, the Programme would analyse the outcomes of the Design Definition documentation. The objective of this activity is to review and confirm the EGNOS HA system design and the service to be provided. In parallel to this review, and Implementation Decision would need to be taken and the EGNOS Service Evolution Plan would need to be updated accordingly.

- Key Decision Milestone 4: Acceptance Review for IOC

  With a duration of 4 months, from January 2027 to April 2027, the Programme would analyse the outcomes of the EGNOS HA service and system development/demonstration. The activity is focused on reviewing the entire system and service implementation, its compliance with the expected configuration and the related service performances. If the approval is achieved, the EGNOS HA service can start the last tests before entering in operation providing the IOC service performance.

- Key Decision Milestone 3.1: System & Service Design Review and implementation decision for FOC

  With the same duration as KDM3, but from January 2027 to June 2027, the Programme would perform the same kind of activities and considerations of KDM3 but focusing on the requirements and the expected performances to be achieved for the FOC service.

- Key Decision Milestone 5: Operational Readiness Review and Service Declaration for IOC

  With a duration of 2 months, from September 2027 to October 2027, the Programme would confirm the readiness of the system and service to provide the IOC performance. If the milestone is successful, EGNOS HA IOC is declared operational.

- Key Decision Milestone 4.1: Acceptance Review for FOC

  With a duration of 4 months, from March 2029 to June 2029, the Programme would perform the same type of analyses of Key Decision Milestone 4 but focusing on the results of demonstration phase, checking if the requirements and the expected performances (tested in demonstration) are achieved for the FOC, through the verification processes.

- Key Decision Milestone 5.1: Operational Readiness Review and Service Declaration for FOC

  From November 2029 to December 2029, the Programme would verify the readiness of the operational procedures of the entire system and service, confirm the positive status of SP condition to comply with the FOC requirements and user performances. If the system is accepted and the service ready to operate, the FOC operation is finally achieved.

The table giving an overview of the activities planned for the implementation roadmap is shown here below.

Table 6-1: EGNOS HA Implementation roadmap activities

PHASE/ DECISION	SCOPE	ACTIVITIES	DURATION
EGNOS HA mission and service analysis	Service & System	Preliminary version of: - User needs - Service Concept - Service & System Requirements - Service Provision Scheme - Service Implementation roadmap - Standardisation Process - Cost-Benefit analysis - Identification of technical uncertainties/lacks/open points and how to tackle them	February 2018 - July 2019 (18 months)
KEY DECISION MILESTONE 1	Internal	Internal decision on EGNOS HA service concept analyses: - Technical and economic feasibility - Consolidate the list of activities required Evaluation of technical uncertainties/lacks/open points	August 2019 - October 2019 (3 months)
Tender Process	Internal	Activities to contract an industry (or a consortium): - Statement of Work preparation - Prior Information (description of the procurement, activities and related duration established for the contractor) - Evaluation and Negotiation - Signature of Contracts	November 2019 - April 2020 (6 months)
Note: the presented tender process aims to contract a company/ consortium to perform the tasks of Technical Feasibility, Requirements Definition & Consolidation, Standardisation and System R&D. Only a single contract is planned thanks to the links between the tasks.			
EGNOS HA technical feasibility	System & Service	Analysis of: - Critical technologies (investigation of the most suitable ones for the HA service) - System and user integrity definition study - Impact on infrastructure (interfaces) and related costs - Evaluate system design options - Detailed version of activities defined in EGNOS HA mission and service analysis	May 2020 - December 2020 (9 months)
EGNOS HA Requirements Definition & Consolidation	System & Service	Activities: - Analysis for potential deployment of ground stations after 2025 - Refinement of minimum number and location of ground stations for both service levels - Analysis of number of HA Processing chains based on RAMS analyses - Requirements for PF (Safety checks, HA processor, Functional safety) - Analysis of GEO replacements (EOL) and number of GEO needed - Definition of protocols for E5b messages - Definition of new protocols due to EDAS adaptation to HA - HA user algorithm study and definition	May 2020 - April 2022 (24 months)

PHASE/ DECISION	SCOPE	ACTIVITIES	DURATION
EGNOS HA Standardisation /Certification and R&D	Standardisation and certification at system level	Activities: - Identification of potential standardisation entities (e.g. CEN/CENELEC) with ISO/ITU, if none of such entities is already contracted. - Identify and handle potential hazards in GNSS constellations - To define and standardise the minimum integrity level of HA processor and encoder (and related characteristics, e.g. TTFF). - To define and standardise the minimum integrity level of data transmission for each broadcasting mean. - Standardisation of Safety Checks algorithms - At HW level, definition of needs for certain equipment. The manufacturing procedure shall be standardised (at system level). - EGNOS HA ICD consolidation - Cross check with user level standardisation	
	System R&D	Activities: - Study for new technologies for 2027+ - Analysis of additional broadcasting means - Analysis of new potential processing technologies	
	Standardisation and certification at user level	Activities: - Identification of potential standardisation entities (e.g. CEN/CENELEC) with ISO/ITU, if none of such entities is already contracted - Consolidation of user level integrity definition in EGNOS HA main applications - Study of standards in force in most relevant sectors / applications and harmonise them through safety cases - Study of Hybridisation effects for most critical applications - At HW and SW level, definition of equipment needs. The receivers manufacturing procedure shall be standardised. - Receiver standardisation at SW and HW level, including safety considerations - Testing and validation of receivers, through demonstration	May 2020 - December 2026 (80 months)
Note: at the end of April 2022, a cross check of the results of standardisation at system and user level is planned. The relevant outcome is the consolidation of the system part. User level standardisation activities will need more time and will last until the Key Decision Milestone 4. Part of such activities will need a testing and validation process of receivers, which will be done through the Service Demonstration task.			
KEY DECISION MILESTONE 2	Internal	System & Service Requirements Review both for IOC and FOC. Requirements are well defined and confirm the Viability of the service. Outcomes are inputs for Tender process for Service Provider.	May 2022 - June 2022 (2 months)
Tender Process for SP	Internal	Activities: - Statement of Work preparation - Prior Information (description of the procurement, activities and related duration established for the contractor) - Definition of service provider's Responsibilities & Liabilities - Definition of Service Level Agreement required for the service provider - Evaluation and negotiation - Signature of Contracts	July 2022 - June 2023 (12 months)

PHASE/ DECISION	SCOPE	ACTIVITIES	DURATION
EGNOS HA **Design Definition**	Service and system	Activities: - System architecture definition - HA PF system design (ODTS and ionosphere) - Design of the control system and monitoring system - Design of safety monitors and checks in the delivery chain - Complete and detailed Risk analysis at system level - Service Definition Document (SDD) writing (start) - Identification and evaluation of sources for reference products to validate the EGNOS HA performances	July 2023 - December 2024 (18 months)
	System	Activities: - Validation of Dissemination channel capabilities (latency, rate)Definition of deployment and (future) adaptation activities for dissemination channels - Definition of deployment and (future) adaptation activities for dissemination channels - Manage of EGNOS V3 deployment - Design of interfaces and security accreditation processes - Security activities - Tender to contract industry for system development Activities related to the infrastructure: - GEOs procurement (with respective PRNs). Duration of 36 months, (GEO5, GEO 6, GEO7). 2 GEOs for operation and one for tests. - Additional RIMS procurement (4 regional + 22 worldwide). Duration of 48 months.	
	Service R&D activities	Service provider: - Study of new user technologies - Study of new service technologies - Analyses of HA algorithm consolidations and updates - Trade-off of ionospheric data algorithm - Test campaigns of receivers with integrated HA algorithm	July 2023 - December 2027 (54 months)
Note: The system design task bases its activities on the outcomes of requirements definition and standardisation activities at system level. Activities which last longer than the Design Definition tasks are the procurements of GEOs and additional RIMS, which will be performed in parallel also with the Implementation activities (need of testing before the complete integration in the delivery chain).			
KEY DECISION MILESTONE 3	Internal	System & Service Design Review for IOC. Once accepted, the design of the system and the service to be provided (with related activities) are well defined and frozen. Everything is ready for the system deployment & Initial service implementation	January 2025 - June 2025 (6 months)
EGNOS HA Implementation	Service	Activities: - Helpdesk and User Support provision plan and preparation - Implementation of processors, alert generators, safety checks and start pre-operation - Service delivery chain service validation tests - Service Definition Document consolidation	July 2025 - October 2029 (52 months)

PHASE/ DECISION	SCOPE	ACTIVITIES	DURATION
	System	Activities: - Ground Segment technical adaptation for EGNOS HA - Complete manufacturing, assembling and integration of system platforms (i.e. processing facility, signal generator, safety checks) - Antennas mounting & calibration user guide - System security activities - System interfaces development and deployment Delta Activities for FOC: - RIMS (included additional ones) firmware upgrade for FOC - Integration and testing of additional RIMS with the network.	
Note: Implementation activities are planned as a continuous process, focused first on the achievement of IOC, and then on FOC through delta activities. Activities at system level shall be prioritised in order to first Service implementation activities are strictly related to the service demonstration ones.			
EGNOS HA Demonstration (Public)	Service	Activities: - System and service operations Non-compliances detection - Service and technology validation - Test-bed of additional dissemination means integration - Fostering E5b implementation for receivers manufacturers - Involvement of entities	July 2025 - December 2029 (54 months)
	System	Activities: - Monitoring of stations' network operational conditions once integrated with EGNOS ground segment. - Testing of user receivers and validation of standards - Testing of new procured GEOs - Testing of additional RIMS before FOC	
Note: Demonstration activities will be performed in parallel with the implementation task, at system and service level. In this way, demonstration activities will work as a testing/validation process of the entire service delivery chain. Demonstration will continue also during the IOC, because other tests will be needed due to delta activities for FOC (e.g. RIMS firmware update)			
KEY DECISION MILESTONE 4	Internal	Acceptance Review for IOC. Once accepted, the system has been approved to be implemented and operated.	January 2027 - April 2027 (4 months)
KEY DECISION MILESTONE 3.1	Internal	System & Service Design Review for FOC. Once accepted, the design of the system and the service to be provided (with related activities) are well defined and shall not be modified. Everything is ready for the system deployment & FOC service implementation	January 2027 - June 2027 (6 months)
EGNOS HA service promotion	Service	Activities: - Service Definition Document validation and publication (1st version) - Service promotion - Acceptance, deployment and pre-operational activities	May 2027 - August 2027 (4 months)
KEY DECISION MILESTONE 5	Internal	Operational Readiness Review for IOC. Once accepted, the system has been approved to be deployed and operated.	September 2027 - October 2027 (2 months)

PHASE/ DECISION	SCOPE	ACTIVITIES	DURATION
EGNOS HA Initial SL (IOC)	Service	Activities: - Operations 24/7, monitoring and maintenance - System updates - Helpdesk activities and user Support	November 2027 - December 2029 (25 months)
KEY DECISION MILESTONE 4.1	Internal	Acceptance Review for FOC. Once accepted, the system has been approved to be deployed and operated.	March 2029 - June 2029 (4 months)
EGNOS HA service upgrade officialisation	Service	Activities: - Publication of Service Definition Document (2nd version) - Acceptance, deployment and pre-operational activities	May 2027 - August 2027 (4 months)
KEY DECISION MILESTONE 5.1	Internal	Operational Readiness Review for FOC. Once accepted, the system has been approved to be deployed and operated.	November 2029 - December 2029 (2 months)
EGNOS HA Final SL (FOC)	Service	Activities: - Operations 24/7, monitoring and maintenance - System updates - Helpdesk activities and user Support	January 2030 - /

6.2. RISK ANALYSIS

The following risks are related to the potential open points that could take place along the implementation process. Each of the proposed risks has been evaluated through two parameters: Severity and Probability of occurrence, each one divided in 5 categories:

- Severity: Negligible (1), Significant (2), Major (3), Critical (4), Catastrophic (5).
- Probability: Minimum (A), Low (B), Medium (C), High (D), and Maximum (E).

As a consequence, each risk has been classified as Acceptable, Undesirable or Unacceptable, with different mitigating and contingency actions based on the risk priority.

The list of the identified risks (with the correspondent criticality) related to the implementation roadmap follows.

RISK 01 – EGNOS HA unfeasible (A5): The EGNOSHA Technical Feasibility Analysis of the service concludes that the service is not finally feasible due to the risk associated to the existing uncertainties or even the unfeasibility to achieve all requirements proposed for the service.

RISK 02 – Limited network station at regional Level (B3): The number of monitoring stations used to obtain GNSS data to be sent to the HA processing facility at EU Regional level could be not enough to comply with requirements established for each Service Level in certain areas. (44 EGNOS V3 RIMS + 4 edged stations proposed to be distributed in Finland, Baltic countries and Azores islands)

RISK 03 – Limited network station at global level (B3): The number of sensor stations used to obtain GNSS data to be sent to the HA processing facility at global level could be not enough to comply with requirements established for the FOC. Additional 22 worldwide stations to the 44 EGNOS V3 RIMS + 4 additional east EU stations. Difficulties on developing stations outside EU area shall be taken into account.

RISK 04 – Technical and Operational requirements unachieved (C4): The results of technical analyses do not confirm the achievability of some requirements. It may happen that from a timeline point of view, the technology is still not ready for the planned implementation date of a certain SL. From a feasibility point of view, there is a possibility of blocking the implementation progress for the non-compliance at integrity level. Main topics considered are:

- Three frequencies technology will not be available in 2030
- GPS III deployment for 2030 (FOC) not fully achieved
- User level algorithm not able to reach targeted PLs and TIRs

RISK 05 – Difficulties in standardization and certification of EGNOS HA receivers along all sectors (D4): The number of sectors in which EGNOS HA could be applied, the lack of standards and Certification authorities for HA topic, the differences and non-compliances between the given sectors could lead to difficulties regarding the achievement of a harmonised standard for EGNOS HA high accuracy integrity and of receivers' manufacturing processes.

RISK 06 – EGNOS HA Requirements not achieved (B3): The results of Requirements definition and standardisation activities are not satisfactory and the System & Service Requirements Review cannot be achieved as scheduled.

RISK 07 – Difficulties in identification of sources for reference products (C2): Accurate clock, orbit, and TEC products are needed to be validated through a comparison with reference products. The missing of such source would not allow the service provision.

RISK 08 – Difficulties in procurement of User-level algorithm (D4): The HA algorithm shall be defined in a similar way as it is done for SBAS (MOPS), but requirements are needed to be imposed to the equipment to ensure the probability of threats on the user side. Each threat would reflect in a different way to the PL, but the wide quantity of scenarios and external conditions affecting user level performances, the inexistence of standards (at the day of writing the present document) ensuring the operational safety with the required TIR and PLs, let this algorithm be difficult to provide.

RISK 09 – Proposed broadcast channels not ready for IOC (C2): The proposed broadcasting channels (Internet and EGNOS E5b) shall be implemented for the IOC as defined in the present implementation roadmap. Activities for protocols definition and adaptation to HA are planned but, despite this, broadcasting means could not be ready to be implemented for such date. The cause would be the possible delay in the proper broadcasting channel implementation roadmap such as, in example, formalisation of Internet channel for the HA data provision or validation of E5b HA message structure.

RISK 10 – EGNOS V3.1 not ready for 2024 (B4): EGNOS HA service would need stations raw data, which is part of EGNOS V3.1 and its implementation is planned for 2024. A possible delay could be a risk to consider for the High Accuracy implementation process. As the only result would be an EGNOS HA delay in cascade on the roadmap, some mitigations actions shall be needed to avoid it.

RISK 11 – Unavailability of worldwide station network (B4): For the proper generation of HA data, a global station network sparsely distributed is required. Within the EGNOSHA project, different configurations and distributions have been studied (e.g. GSS), but further activities shall be performed to understand if agreements of multiple networks could be reached. Given this uncertainty, it is pertinent to open a risk until a decision on deploying new stations, using GSS or procuring external data under an SLA is decided.

RISK 12 – New proposed broadcasting channels not validated for SoL service (C3): The proposed broadcasting channels chosen during System Design Definition phase shall ensure the availability and robustness required for a SoL service.

RISK 13 – EGNOS HA Key Decision Milestone not achieved (B4): The expected results for the Key Decision Milestone are not satisfactory or related activities need more time to comply with expected outcomes. This imply that such Key Decision Milestone cannot be achieved as scheduled. Such Risk is considered valid for each of the KDM identified along the Implementation Roadmap, exception done for Service Concept Review considered in RISK 01.

A concise Risk Matrix of the above presented risks is shown here below (Green: the risk is considered Acceptable; yellow: risk is Undesirable; red: risk is Unacceptable). Unacceptable risks (05 and 07)

need further activities, planned along next phases of the implementation roadmap, in order to lower their criticality. Indeed, HA algorithm procurement and its standardisation are identified as the major open points.

Table 6-2 EGNOS HA Risk Matrix

		SEVERITY				
		1	**2**	**3**	**4**	**5**
PROBABILITY	**E**					
	D				**RISK 05** **RISK 08**	
	C		**RISK 09**	**RISK 07** **RISK 12**	**RISK 04**	
	B			**RISK 02** **RISK 03** **RISK 06**	**RISK 10** **RISK 11** **RISK 13**	
	A					**RISK 01**

6.3. CRITICAL PATH

The last stage of the EGNOS HA implementation roadmap analysis is the identification of the critical path. This is referred to the sequence of activities with the greatest risk to provoke delays along the roadmap, considering the related interdependencies and associated risks. Based on the timeline shown in Figure 6-1 and the activities listed in Table 6-1, the result of the critical path analysis is the one depicted in the following figure. Please note that the diagonals represent the parallelisation of the activities, which are part of the same task (e.g.: Standardisation at user level and testing).

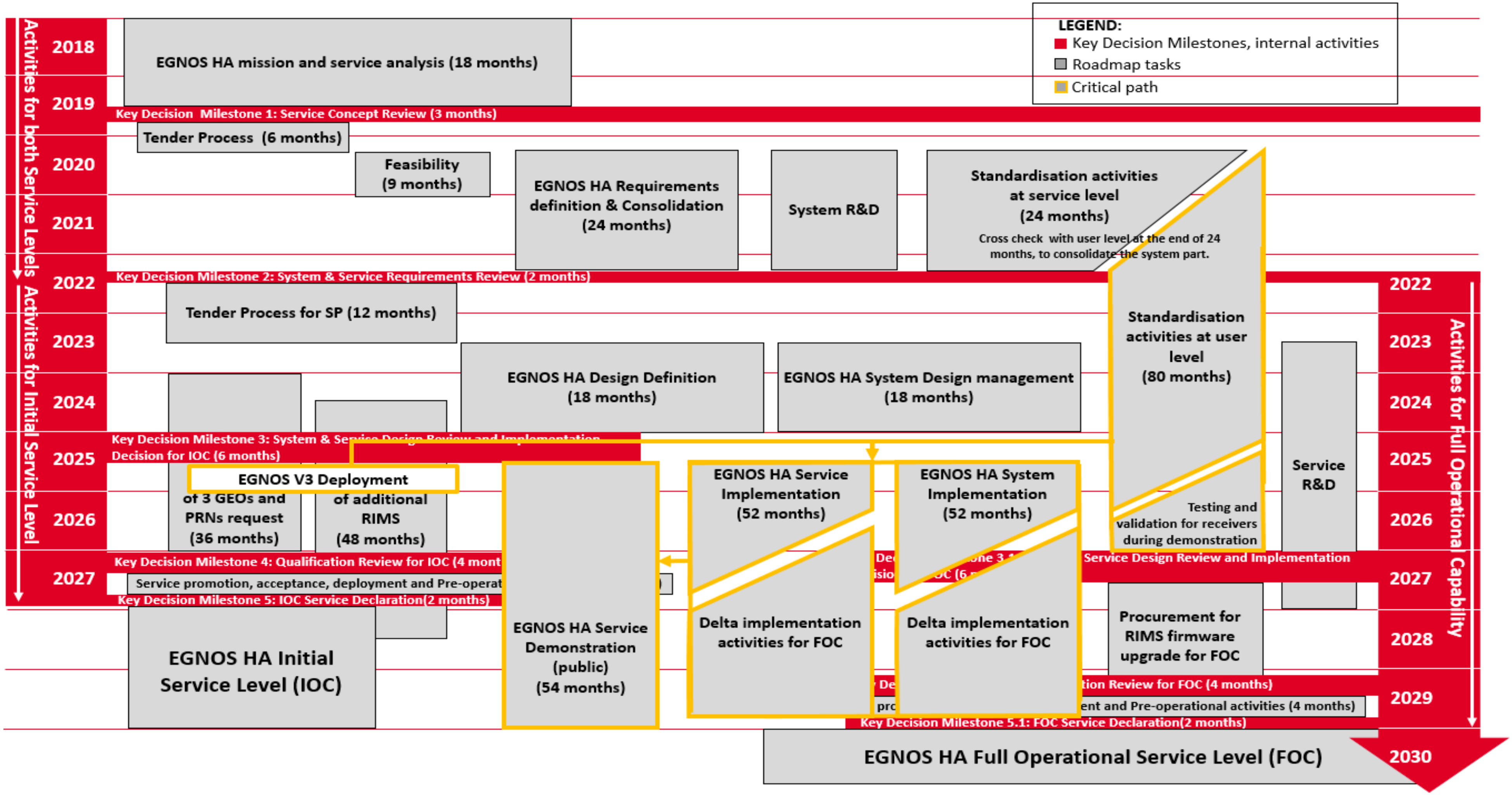

Figure 6-2: EGNOS HA Critical path (yellow line)

As shown, the critical path starts at the very early stages of the roadmap. In the path highlighted in yellow, it has been considered the series of tasks/activities which could be affected by delays of related activities as a cascade effect or some events that are not directly referred to the EGNOS HA implementation roadmap itself. Other activities included in the critical path are those ones whose criticality is considered as a risk for the entire implementation process. The critical path activities of the EGNOS HA implementation roadmap have been considered as all those tasks/activities which could be affected by delays of interdependent activities or some events that are not directly referred to the EGNOS HA implementation itself. Other activities included in the critical path are those ones whose criticality is considered as a risk for the entire implementation/programmatic process. Some criticalities are:

- **Standardisation and certification activities**: As shown in previous figures, standardisation and certification activities are split into system and user standardisation activities, due to the different workload. While the system standardisation activities shall be completed for KDM2, the user standardisation activities are more arduous and subject to more risks. In fact, they are planned to be re-iterative, strictly linked to other tasks (e.g.: testing and validation of receivers through demonstration activities) and critical for the entire implementation. For example:
  - The recommended co-operation with receivers' manufacturers could represent an advantage thanks to their expertise and their involvement which could catalyse the implementation of the service but, it could also represent a constraint because of a direct dependence of an external source, which could lead to roadmap delays due to the complexity of the HA algorithm obtainment.
- **EGNOS V3 deployment**: EGNOS V3.2 deployment is planned to be accomplished in 2025 but its operational readiness (ground stations, GEO satellites, interfaces and related SLAs) shall be achieved in 2026. Considering that EGNOS HA service should be dependent on this external activity, this link is considered as a relevant part of the entire critical path, assuming that the EGNOS V3 roadmap could be affected by certain delays which would consequently delay the EGNOS HA implementation.
- **EGNOS HA System / Service implementation**: As a cascade effect, if EGNOS V3 would not achieve the FOC from 2026 for uncertain reasons, this would affect the present roadmap phases from such year on. Part of the EGNOS HA Implementation activities at system and service level would be limited, delayed or even blocked and this would cause more relevant delays in further phases of the roadmap, including the start of IOC operations. In particular:
  - Technical adaptations and security accreditation activities and/or system interfaces deployment between EGNOS HA and EGNOS ground segment could not be fully performed
  - The implementation of several integrity checks in the delivery chain could not be fully performed
- **EGNOS HA service Demonstration**: The standardisation/certification activities and EGNOS V3 status activities reconnect in the implementation/demonstration phase, as a cascade effect. If one of the two branches is not fully completed and/or the expected outcomes are not achieved, the demonstration phase would be affected by delays.

It is understood that the criticality of the EGNOS HA Implementation and Demonstration activities could affect the activities from 2025 on, as a cascade effect, with increasing criticalities and cost impacts because of the need of more relevant contingency actions and efforts.

7. COST BENEFIT ANALYSIS

Within the EGNOSHA project, "**Costs-Benefits Analyses (CBAs)**" of the EGNOS HA service were conducted from both potential service providers and end-user points of view. In this context, service providers are mainly new entities/ comers offering EGNOS HA to the market, while end-users are the potential customers benefiting from the use of EGNOS HA or from products/services based on it.

To draft the CBAs, different **sources** were used. The completeness of different sources allowed covering the key scope of the analysis and validating information. For this reason, the CBAs rely on:

- The interactions with the stakeholders, based on an interview program to collect a preliminary feedback on EGNOS HA features and CBA items (c.170 questionnaires sent and more than 20 answers received) and an open consultation (with interested stakeholders) to validate the CBA results;
- The Consortium know-how, especially to define the EGNOS HA service features, deployment and costs; and
- A deep desk-research to complement inputs from primary research.

Data collated from interviews, consortium know-how and desk analysis have been merged and elaborated leveraging ALPHA expertise and using the CBAs conceptual frameworks based on some main **assumptions**, i.e.:

- The use cases: the selected domains/ applications as reported in section 2. ;
- The features: the EGNOS HA user performances as reported in subsection 4.1.1;
- The base case scenario: EGNOS HA provided for free;
- The service area: EU28; and
- The timeframe: 2025-2035.

Starting from these assumptions, the CBAs estimated the total **addressable and target market** of EGNOS-HA per application, the main **investments** necessary for the adoption and provisioning of EGNOS-HA and the costs that can be positively impacted by EGNOS-HA service, coupled with **related savings**.

The overall **market** and the rated **uptake/ penetration of EGNOS-HA service** vary by domain and application, as summarised in the table below.

Table 7-1: EGNOS-HA addressable market and potential penetration

Domain	Application	EGNOS-HA service (in EU)	
		Addressable market (over 2025-2035 period)	Potential penetration (over 2025-2035 period)
Surveying & mapping	Construction – Machine Control	From 76 490 to about 200 000 installed-base of GNSS devices	Less than 5%
Agriculture	Automatic Steering	From 317 078 to more than 426 000 high-end tractors[4] (only new and last-five years old tractors considered)	Up to 10%
	Farm Machinery Guidance		
	VRA-low		Up to 17%
	VRA-high		
LBS	LBS applications for smart utilities	More than 240 smart cities per year	Up to 45%
Road	Automated driving	More than 1.5 million high-end cars per year	Up to 30%
Rail	Automatic Train Operations	From 65 387 to more than 79 000 locomotives and railcars	Up to 20%
Maritime	Autonomous vessels	A stock of 180 vessels	100%

[4] Tractors could be counted more than once for different applications

Domain	Application	EGNOS-HA service (in EU)	
		Addressable market (over 2025-2035 period)	Potential penetration (over 2025-2035 period)
	Bridge collision avoidance – Inland Waterways	About 1 000 vessels (new and most advanced vessels considered) per year	Up to 60%
	Port operations - automated docking	An average of 500 new sea vessels per year	Up to 40%
UAV	Goods delivery	From 5 000 to more than 70 000	Up to 35%

Even if provided for free, to adopt or provide the EGNOS-HA service:

- **End-users** will need to perform some **initial investments (CAPEX).** While diverse users from different segments will present similar types of investments, the related amount might change according to different domains. Actually, the main CAPEX for end-users to start up with the adoption of the proposed service are the device/ equipment (i.e. receiver and antenna) price and one-off costs for service implementation (i.e. lump sum for the all the activities necessary to implement the service, such as the upgrade of the system where the EGNOS-HA-enabled receiver will work, integration with other sensors, "unlock" specific functions, just to mention some examples). In particular, **the price of the device/equipment can strongly vary, from 40 EUR per car in road domain up to more than 7 000 EUR per unit in surveying or for UAVs**, and can impact the final results of the CBA. This difference mainly depends on the possibility to reach (or not reach) significant efficiencies (e.g. economies of scale) in specific domains (such as in case of road), with costs per unit of output decreasing with increasing scale. In this context, the European Commission can play a key role. In fact, the end-users involved in the interview program highlighted that a faster adoption can be foreseen in case of **EC funding initiatives (e.g. grants/ contracts and/ or procurements) aimed at financially sustaining their initial investments** (esp. the device/ equipment price), maximising their benefits and positively impacting the overall domains. In line with that, all those actions aimed at reducing the costs (and, consequently, the price) of the user equipment are warmly suggested. Some examples are: the promotion of receivers and antenna prototyping activities, the use of dual and triple frequency devices for new services, the creation of economy of scales or the enhancement of competition in the HA market at equipment level.
- **Service providers**. As the end-users, the service providers suggested a free-based service, not intending to charge a fee for the service to their customers. Therefore, once contracted by the European Commission, the possibility to **cover the initial investments through this contract/ procurement will be of paramount importance for these actors.** As matter of fact, to become the EGNOS-HA service provider(s), they should sustain both fixed and variable costs:
  - **CAPEX:** they are mainly related to the reference stations deployment, HA processing centres, development of additional/new features, esp. in case of a fee service and new interfaces with EGNOS and other dissemination channels. These costs could range **from 1 million EUR to more than 9 million EUR, depending on the service provider considered**;
  - **OPEX:** they include reference station network site maintenance and operation costs, processing centres site maintenance costs, nominal operations and evolution costs and personnel and training cots. They can be assed in the **range of 2-3.5 million EUR per year**.
- In addition to these actors, the involvement of **receiver manufacturers** in the next phases of EGNOS-HA development and related pilot projects will be fundamental, since they should invest in EGNOS HA enabled receivers (before they start selling their products).

Last but not least**,** costs that can be positively impacted by EGNOS-HA service, coupled with related **savings** have been also considered. In particular, the CBAs estimated the annual costs potentially reduced by EGNOS-HA service and the amount of this reduction. These costs and related benefits might considerably vary in both type and size according to different domains/ applications. A quali-quantitative analysis (by domain and application) has been done for the benefits reported in the table below.

Table 7-2: Benefits by domain

Domain (Application)	Application	Potential benefits
Surveying & mapping	Construction – Machine Control	5% of reduction of cost for construction activities (thanks to an increase of automation)
Agriculture	Automatic Steering Farm Machinery Guidance VRA-low VRA-high	Depending on the application: • From 0% to 2% of reduction of costs for tractor usage • From 40% to 60% of reduction of costs linked to RTK equipment
LBS	LBS applications for smart utilities	• Max. of 10% of reduction of costs for street maintenance and waste collection and recycling • Max. of 15% of reduction of cost for water management
Road	Automated driving	• About 1% of reduction of costs for fuel overconsumption, for delay and for accidents • Max. 5% of reduction of costs for LIDAR
Rail	Automatic Train Operations	• Increase of profitability for trains operators (additional trains per line) • Max. 5% of reduction of part of ERTMS costs • An average of 1.5% of reduction of costs for energy consumption • Max. 6% of reduction of cost for manual operations • Reduction of costs for delay
Maritime	Autonomous vessels Bridge collision avoidance – Inland Waterways Port operations - automated docking	Depending on the application and year: • From 30% to 100% of reduction of costs for maintenance & operation, vessels crashing with locks and RTK equipment
UAV	Goods delivery	Max. of 10% of reduction of costs for delivery by UAVs and for premium delivery

Leveraging the quali-quantitative impact assessment, the figure below provides an overview on the level of potential economic benefit brought by EGNOS-HA by domain and application.

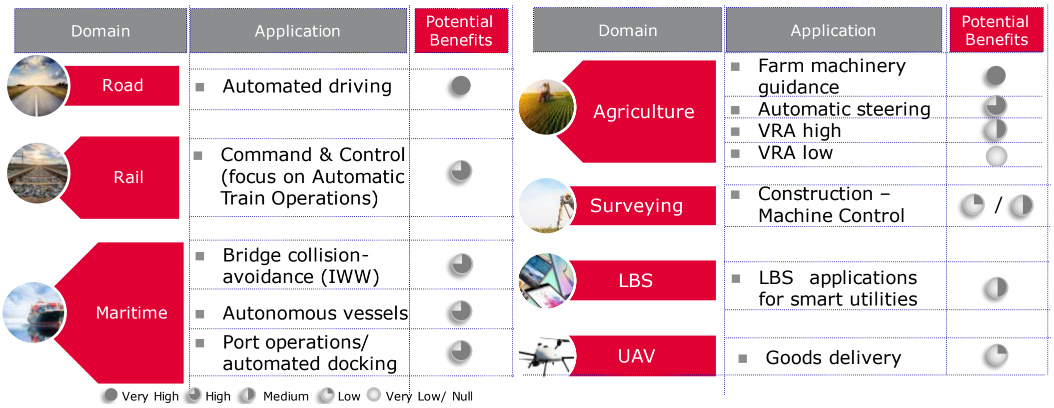

Figure 7-1: Overview on CBAs outcome

To sum up, EGNOS-HA could bring medium/ high economic (gross) benefits to the majority of the domains and a wide adoption is expected, if the service will be provided for free. In fact, stakeholders see a potential added value provided by EGNOS-HA service to almost all domains and applications. In particular, experts consider target integrity, daily availability, position accuracy and convergence time the most interesting EGNOS-HA user performances. Also, they show a very high interest in leveraging both EGNOS-HA and Galileo HA. Moving forwards and comparing both costs and benefits, it can be concluded that different considerations drive the CBAs for the selected applications, especially

regarding the cost of the equipment for end-users and the initial investments for service providers that can strongly vary and impact the final results of the CBA. In this sense, the European Commission can play a key role in supporting both these actors, as better explained above. Moreover, some main findings by domain are:

- **Surveying**: EGNOS-HA could improve the construction machine control application, allowing savings thanks to an automatization of the activities. Even if not in the scope of this analysis, also other applications (e.g. cadastral surveying) could benefit by the proposed service. All in all, EGNOS-HA is seen by some users mainly as a back-up service under specific conditions (e.g. unavailability of alternatives) in this domain;
- **Agriculture**: EGNOS-HA could provide a concrete economic added value for the end users if adopted for farm machinery guidance. On the other hand, no major (net) benefits are expected for VRA applications, and especially for VRA-low;
- **LBS**: EGNOSHA could support the growth of LBS applications for smart utilities, even if these applications do not need high accuracy levels;
- **Road**: Automated driving could strongly benefit by the use of EGNOS-HA. The proposed service can answer to the need of estimating the absolute positioning of vehicles;
- **Rail**: Automatic train operations could be enhanced by EGNOS-HA. Stakeholders suggest to consider the Command & Control application as entry point for the future service adoption;
- **Maritime**: EGNOS-HA could provide an added value for the end users if adopted first of all for autonomous vessels and port operations - automated docking. Moreover, for port operations, pilots and port authorities are good candidates to foster the adoption of EGNOSHA service as an aftermarket solution;
- **UAV**: EGNOS-HA could improve the goods delivery within the UAV domain, allowing savings thanks to a more effective delivery process. Considerations related to the cost of the equipment will be fundamental for this domain.

In this context, the **criteria and challenges for the adoption and provisioning of EGNOS-HA** will depend on the specific market. However, experts from different domains agreed on some general conditions that can foster the uptake of the service, i.e.:

- Free of charge service;
- Not stand-alone solution, but the possibility to use the service together with other solutions (e.g. systems and sensors) already leveraged in the different domains;
- Fast time to market (the proposed timeline perceived a too late entry in the market);
- Satellite and terrestrial distribution;
- Multi-frequency and multi constellation solution;
- Use of open standards and/ or protocols; and
- Expensive tests to demonstrate and validate benefits.

To conclude, the criteria and challenges for the EGNOS-HA adoption and provisioning introduce the **strengths, weaknesses, opportunities and threats** reported in the EGNOS-HA SWOT analysis.

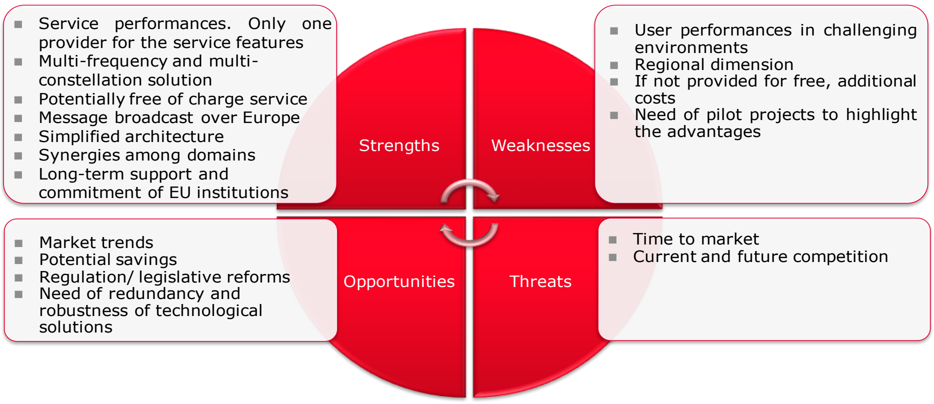

Figure 7-2: EGNOS-HA SWOT analysis

8. CONCLUSIONS

The activities conducted in the EGNOSHA project have given a clear vision of the potential interest, achievable capabilities as well as the existing open points of the EGNOS HA service.

Since the early stages of the study, it has been observed a high interest in the service by the main targeted sectors if the service was able to provide certain targeted requirements (Target Integrity Risk, alarm limit, availability, accuracy and convergence time as listed in Table 3-1). The participation of stakeholders to the study was instrumental to understand users' needs and main expectations.

Two services were defined: an initial service (IOC) with reduced performance which could be implemented in a relatively short timeframe (2027) to improve the time-to-market and exploit EGNOS V3 available capabilities (e.g. a dense network of reference stations); a full operational service (FOC) which would target more demanding performance to attract several key sectors but would need more time to be deployed (2030). From a service provision perspective, the FOC service will be backward compatible with the IOC one, thus no major changes on the signals or data dissemination is expected; however, specific changes on the system and user algorithms would be needed.

Finally, the project highlighted a few key open points, which should be addressed as part of the activities identified in the service implementation roadmap:

- The analyses performed during the project demonstrated that the proposed requirements might be met in the next years, save for the very demanding TIR and alarm limit target values proposed for the FOC service in 2030 which cannot be met using the state of the art technology but could be achievable in the future. As Integrity is the key differentiator of EGNOS HA service, the consortium recommended to carry out safety studies in the earliest phases of the design as described in the service implementation roadmap.
- Specific standardisation activities at service and user level are needed to solve the lack of harmonisation among standards, the lack of certifying bodies on targeted sectors, and the unclear split of liabilities between the service provider (committed performance) and the user (standardised receiver). The consortium proposed to consider standardisation activities at service/system level and at user level and recommended to start collaborations with receivers' manufacturers and other key stakeholders (RTCM, certification bodies, competent authorities, etc.) in the early stages of the service implementation roadmap.
- HAPS (High Altitude Platform Station) seems an attractive dissemination channel of the EGNOS HA FOC service to reach remote areas without internet access or with low GEO visibility (e.g. high latitudes). However, since HAPS technology is still not mature for navigation purposes, further R&D studies would be needed.
- Further discussions with key stakeholders should be carried out in order to understand the potential impact of EGNOS HA FOC service on the market.

ANNEX A. ACRONYMS

Acronyms used in the present document are included in the following table:

Table 8-1: Acronyms

Acronym	Definition
ARNS	Aeronautical Radio Navigation Service
HA	High Accuracy
BPSK	Binary Phase Shift Keying
CAPEX	CAPital Expenditure
CBA	Cost Benefit Analysis
CENELEC	European Committee for Electrotechnical Standardisation
CS	Commercial Service
DFMC	Dual Frequency Multi-Constellation
DOP	Dilution Of Position
EC	European Commission
EDAS	EGNOS Data Access System
EGNOS	European Geostationary Navigation overlay System
EGNOS HA	EGNOS High Accuracy
EOL	End Of Life
ERA	European Railway Agency
ESA	European Space Agency
EU	European Union
FDE	Fault Detection and Exclusion
FEC	Forward Error Correction
FOC	Full Operational Capability
GEO	Geosynchronous Earth Orbit
GNSS	Global Navigation Satellite System
GSA	European GNSS Agency
GSS	Galileo Sensor Station
HAPF	High Accuracy Processing Facility
HAPS	High Altitude Platform Station
HAS	High Accuracy Service
HW	Hardware
ICD	Interface Control Document
IEC	International Electro-technical Commission
IMO	International Maritime Organisation
IMU	Inertial Measuring Unit
IOC	Initial Operational Capability
ISO	International Standard Organization
ITU	International Telecommunication Union
KDM	Key Decision Milestone
KPI	Key Performance Indicator
LBS	Location Based Services
LIDAR	Laser Imaging Detection And Ranging
LOS	Line Of Sight
MEO	Medium-Earth Orbit

Acronym	Definition
MOPS	Minimum Operational Performance Standards
ODTS	Orbit Determination & Time Synchronization
OPEX	OPerating EXpense
PL	Protection Level
PPP	Precise Point Positioning
PRN	Pseudo-Random Noise NUMBER
PTP	Point-To-Point
R&D	Research & Development
RAIM	Receiver Autonomous Integrity Monitoring
RAMS	Reliability, Availability, Maintainability, and Safety
RIMS	Ranging Integrity Monitoring Station
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Commission for Maritime services
RTK	Real-Time Kinematic
SBAS	Satellite Based Augmentation System
SDD	Service Definition Document
SLA	Service Level Agreement
SoL	Safety of Life
SW	Software
SWOT	Strengths Weaknesses Opportunities Threats
TEC	Treaty of the European Community
TECU	Total Electron Content Unit
TFEU	Treaty on the Functioning of European Union
TIR	Target Integrity Risk
TTFF	Time To First Fix
UAV	Unmanned Aerial Vehicle
VDES	VHF Data Exchange System

ANNEX B. DEFINITIONS

Used terms needing a definition in the present document are included in the following table:

Table 8-2: Definitions

Concept / Term	Definition
RTK	Differential GNSS technique which provides high positioning performance in the vicinity of a base station (max 20 km around the station)
PPP	Global precise positioning service using current and coming GNSS constellations. PPP requires the availability of precise reference satellite orbit and clock products using a network of GNSS reference stations distributed worldwide.
PPP-Integer Ambiguity Resolution + Atmospheric Information	PPP algorithm solution in which the ambiguity of the phase is calculated as an integer number and vertical ionospheric data is used as an input of the algorithm instead to be estimated from scratch. The advantage respect PPP is an improved convergence and more precise solution
Accuracy	The accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of that position with the true position, velocity and/or time of the craft. Since accuracy is a statistical measure of performance, a statement of navigation system accuracy is meaningless unless it includes a statement of the uncertainty in position that applies.
Convergence Time	Convergence time is the time required to reach the solution with a certain accuracy
Availability	The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigation signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.
Integrity	Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation.
Alert Limit	The alert limit for a given parameter measurement is the error tolerance not to be exceeded without issuing an alert.
Time to alert	The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert.
Target Integrity Risk	Probability that, at any moment, the position error exceeds the Alert Limit
Protection Level	Statistical bound error computed so as to guarantee that the probability of the absolute position error exceeding said number is smaller than or equal to the target integrity risk.

ANNEX C. LIST OF RERERENCE AND APPLICABLE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document:

Table 8-3: Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	User Needs, Market Forecast &Competitive Analysis	EGNOSHA-D110	3.2	19/12/2018
[RD.2]	High Accuracy Service Provision Scheme	EGNOSHA-D210	3.1	30/09/2019
[RD.3]	High Accuracy Service Requirements	EGNOSHA-D220	3.1	30/09/2019
[RD.4]	High Accuracy Service Implementation Roadmap	EGNOSHA-D230	2.1	30/09/2019
[RD.5]	CBA For Target Users	EGNOSHA-D310	2.1	30/09/2019
[RD.6]	CBA For Service Providers	EGNOSHA-D320	2.1	30/09/2019
[RD.7]	GALCS - Galileo Commercial Service Specification	GALCS-GMV-D10	1.1	17/07/2013
[RD.8]	Galileo Commercial Service and Open Service Navigation Message Authentication Information Note	-	1.1	01/12/2015
[RD.9]	CESAR - Commercial Service preliminary user requirements document	D10	1.1	11/04/2013
[RD.10]	EGNOS EDAS	D110	4.0	31/10/2017
[RD.11]	Report on Surveying User Needs and Requirements	GSA-MKD-SM-UREQ-229766	1.4	01/03/2018
[RD.12]	Report on Agriculture User Needs and Requirements	GSA-MKD-AGR-UREQ-233667	1.4	28/02/2018
[RD.13]	Report on Location-Based Services User Needs and Requirements	GSA-MKD-LBS-UREQ-233604	1.0	28/02/2018
[RD.14]	Report on Road User Needs and Requirements	GSA-MKD-RD-UREQ-233537	1.2	01/03/2018

END OF DOCUMENT