



NAVIGATION  
MADE IN  
EUROPE

EUROPEAN GNSS (GALILEO)

# OPEN SERVICE SERVICE DEFINITION DOCUMENT

Superseded

## TERMS AND CONDITIONS OF USE OF THE GALILEO OPEN SERVICE

The Galileo OS, unless augmented by certified or otherwise legally approved dedicated systems designed to this effect, has been designed and can only be used for non-safety critical purposes, i.e. purposes that have no impact on the safety of human life and where an underperformance in availability, continuity, accuracy and/or integrity of the Galileo SIS could not cause any kind of direct or indirect personal damage, including bodily injuries or death.

### Scope of Galileo OS Commitment

Although care has been taken in designing, implementing and operating the system, as well as in providing the OS, the OS is not meant to offer any service guarantee to the users.

The minimum level of performance against which the system has been validated and is operated, as well as data of actual performance of the OS are expressed in this document in statistical values that are valid under assumptions described in the Galileo OS SDD. The Commission reserves the right to revise the Galileo OS SDD should these assumptions change or to reflect changes in performance during the deployment of the Galileo infrastructure. This commitment regarding the minimum level of performance shall be without prejudice to the disclaimer of liability below, measures potentially affecting service availability that may be taken either by the Security Accreditation Board, or according to the Council decision 2014/496/CSFP, or in the interests of Member States' national security.

The European Union plans to take all necessary measures for the foreseeable future to maintain or exceed the minimum levels of the OS performance described herein.

The minimum level of performance of the Galileo OS, as specified in the Galileo OS SDD, is obtained under the condition that the user equipment processes the health and status flags as described in section 2.3.1.3 and only uses signals declared "HEALTHY". The users are also reminded that important notices (Notice Advisory to Galileo Users – NAGUs and Service Notices) are published through the Galileo service centre which shall be taken into account when planning to use the Galileo OS for any purpose.

### User responsibilities

The user retains his responsibility to exercise a level of care appropriate with respect to the uses he intends to make of the Galileo OS, taking into account the considerations outlined above.

The users are reminded that the timing and positioning performance they will experience is also driven by other parameters outside the control of the Galileo OS provider (e.g. signal propagation errors or user receiver induced errors) which have to be taken into account when deciding to use the Galileo OS for a given purpose.

Before any use of the Galileo OS, users should study this document in order to understand how they can use the service, as well as to familiarise themselves with the performance level and other aspects of the service they can rely on, in particular the Annex C.4 for a more comprehensive discussion of the relationships between the Galileo OS performance and the end user PVT performance expectations.

In case of doubt, the users and other parties should contact the Galileo helpdesk (see section 1.6.4 for contact details) and their user equipment manufacturer.

### Disclaimer of liability

As the owner of the Galileo system, the European Union - including any of its institutions, offices or agencies, such as the European Commission, the European GNSS Agency (GSA), and other entities acting on the basis of a contract or agreement with the European Union involved in the Galileo OS service provision - does not offer any warranties of any kind (whether expressed or implied) with respect to the Open Service, including, but not limited to, the warranties regarding availability, continuity, accuracy, integrity, reliability and fitness for a particular purpose or meeting the users' requirements. No advice or information, whether oral or written, obtained from the European Union - including any of its institutions, offices or agencies, such as the European Commission, the European GNSS Agency (GSA), and other entities acting on the basis of a contract or agreement with the European Union involved in the Galileo OS service provision - shall create any such warranty.

By using the Galileo Open Service, the user accepts and agrees that the European Union - including any of its institutions, offices or agencies, such as the European Commission, the European GNSS Agency (GSA), and other entities acting on the basis of a contract or agreement with the European Union involved in the Galileo OS service provision - shall not be held responsible or liable for any damages resulting from the use of, misuse of, or the inability to use the Galileo Open Service, including, but not limited to, direct, indirect, special or consequential damages, including, but not limited to, damages for interruption of business, loss of profits, goodwill or other intangible losses, other than in accordance with Article 340 of the Treaty on the Functioning of the European Union.

## DOCUMENT CHANGE RECORD

REASON FOR CHANGE	ISSUE	REVISION	DATE
First issue	1	0	December 2016
The text of various sections of the document has been improved. New parameters and respective Minimum Performance Levels have been added, specifically the Availability of the Position Dilution of Precision and the Availability of Positioning and UTC Service. As a consequence, the Minimum Performance Level for the Availability of Ranging Service has been removed.	1	1	May 2019

## FOREWORD

This “Galileo - Open Service - Service Definition Document” (Galileo OS SDD) defines the Minimum Performance Levels (MPLs) of the Galileo Open Service (OS).

This document supersedes the “Galileo Initial Services – Open Service – Service Definition Document”.

The document will be updated in the future to reflect further changes and improvements of the Galileo Open Service, in particular during the deployment of the Galileo system infrastructure, until the Full Operational Capability (FOC) is achieved.

Superseded

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The background of the slide features a photograph of several large satellite dish antennas. The dishes are silhouetted against a dramatic sky at sunset or sunrise, with a warm, golden light and scattered clouds. The antennas are mounted on complex support structures. A large, semi-transparent red watermark with the word "Superseded" is oriented diagonally across the center of the image, partially obscuring the text and the dishes.

# SECTION 1: THE GALILEO OPEN SERVICE

Galileo is the European Global Navigation Satellite System (EGNSS), under civil control, that provides satellite positioning services to European citizens and worldwide.

Galileo provides ranging signals in three different frequency bands, enabling single- and dual- frequency positioning for users equipped with suitable receivers.

As one of the services offered by Galileo, the Galileo Open Service (OS) enables free of charge, global ranging, positioning and timing, by means of the Galileo OS Signal-In-Space (SIS).

In order for users to be able to benefit as early as possible from the Galileo services, the Galileo Initial Services provision phase started before the Galileo core infrastructure was fully deployed, in 2016. Since then, in parallel to the infrastructure deployment, the performance of the Galileo Services has improved. This Service Definition Document describes the Galileo Open Service provided at the time of its publication. Future releases of this document will be issued to properly take into account the further evolution of the Galileo OS.

## 1.1 PURPOSE OF THE DOCUMENT

The purpose of this Galileo Open Service – Service Definition Document is to describe the characteristics and performance of the Galileo OS provided through the Galileo OS SIS. The OS SDD presents the Minimum Performance Levels (MPLs) targeted for such service and defines the conditions under which such MPLs can be reached. This document addresses all users of Galileo OS. The Galileo OS is provided free of charge to all users.

This OS SDD consists of a main body and five annexes. It provides an overview of the EGNSS program as well as an overview of the OS SIS. It then presents the Minimum Performance Levels for the OS. It concludes with the relevant reference documents. The annexes provide additional information on Galileo OS and about the expected performance at FOC.

The main document comprises the following sections:

### 1) The Galileo Open Service

The main purpose of this section is to introduce the document, define the Galileo Open Service

and to provide a general description of the Galileo system.

### 2) Galileo Open Service SIS Characteristics and Minimum Usage Assumptions

This section includes a description of the Galileo SIS and the definition of the parameters used to identify the MPLs.

### 3) Galileo OS Minimum Performance Levels

This section provides the Galileo Services – Open Service Minimum Performance Levels and describes additional OS SIS functionality.

The following Annexes close the document:

- Annex A: Reference Documents.
- Annex B: Abbreviations and Acronyms.
- Annex C: OS SIS Background Information and PVT Accuracy Performance Drivers.
- Annex D: Galileo Open Service – Performance Evolution.
- Annex E: Description of Notice Advisory to Galileo Users.

## 1.2 SCOPE OF THE DOCUMENT

This Galileo OS SDD applies to the Galileo OS as provided at the time of its publication. This document does not address Galileo restricted access signals such as the E1A signal or the signals broadcast in the E6 band.

The OS SDD belongs to the series of Galileo Programme Reference Documents published for the benefits of Galileo users, to present and explain various aspects of the EGNSS concerning Galileo OS. The other Programme Reference Documents are:

- The European GNSS (Galileo) – Open Service – Signal In Space Interface Control Document (Annex A [1] (OS SIS ICD)):

By describing exhaustively the SIS, it specifies the interface between the Galileo Space Segment and the Galileo User Segment. It is addressed to the whole Galileo OS user community.

- The European GNSS (Galileo) - Open Service - Ionospheric Correction Algorithm for Galileo Single-Frequency Users (Annex A [2]).

It describes in detail the reference algorithm to be implemented by user receivers to compute the Galileo ionospheric corrections. It is addressed mainly to Galileo OS receiver manufacturers.

All public Galileo Programme Reference Documents are made available to users through the web portal of the European GNSS Service Centre (<http://www.gsc-europa.eu>).

## 1.3 TERMS AND CONDITIONS OF USE

The terms and conditions of use of the Galileo Open Service are described at the beginning of this document.

## 1.4 ABBREVIATIONS AND ACRONYMS

Abbreviations and acronyms used in this document are provided in Annex B.

## 1.5 GALILEO OPEN SERVICE DEFINITION

The Galileo Open Service is a free of charge global ranging, positioning and timing service. Each Galileo satellite transmits navigation signals (Signal-In-Space, SIS) in three frequency bands. The OS SIS, broadcast on two out of these three bands, provide access to the Galileo OS ranging, positioning and timing services for

users equipped with a Galileo OS compatible receiver. The following services are supported by Galileo OS SIS:

- Single-Frequency and Dual-Frequency Ranging,
- Single-Frequency and Dual-Frequency Positioning,
- UTC Time Determination.

OS are provided in either single-frequency (SF) or dual-frequency (DF) mode. In the case of SF usage mode, the user equipment tracks and processes the information provided by only one of the three OS frequencies (see 2.2 for more details). The different OS single-frequency usage modes are E5a (only), E5b (only) and E1 (only). In any SF usage mode, specific compensations need to be applied: Broadcast Group Delay (BGD), to compensate for specific satellite systematic delays between the different frequencies, and ionospheric compensation, to compensate for atmospheric delays of the signals. The respective algorithms are specified in the Galileo OS SIS ICD (Annex A [1]) and in the Ionospheric Correction Algorithm for Galileo Single-Frequency Users (Annex A [2]).

In the case of DF usage mode, the user equipment tracks and processes the information provided by two of the three OS frequencies. The different OS dual-frequency usage modes are E1/E5a and E1/E5b. In dual-frequency usage modes, BGD compensation is not required, and ionospheric delays are measured directly by Galileo OS receivers, making use of the dispersive property of the ionosphere.

### 1.5.1 GALILEO OS RANGING SERVICE

Ranging allows users to continuously estimate their distance to the satellite. This measure is the core of positioning-based services since the user's position and time can be estimated using ranging measurements from (at least) four different satellites. GNSS ranging services comprise a set of electromagnetic signals transmitted by satellites and properly modulated to carry the information, generated by an appropriate ground infrastructure, needed by receivers to estimate the user-to-satellite range. The minimum level of expected performance in accuracy and availability of range estimation will constantly improve during the deployment of Galileo system until its final configuration is reached.

The Galileo OS Ranging Service is provided in both SF usage mode and DF usage mode.

DF usage mode is in general characterised by higher accuracy of the range measurement. The use of two frequencies permits in most cases a better compensation of the disturbing effect of the ionosphere on the SIS, thus providing better performance to the end user.

The Galileo OS Ranging Service is interoperable with GPS ranging services and therefore it provides a direct benefit to users who are able to exploit both Galileo and GPS constellations, by increasing the number of available signals-in-space.

## 1.5.2 GALILEO OS POSITIONING SERVICE

By properly combining the ranging and timing measurements, all users equipped with a Galileo OS receiver who are located within the Service Volume of the Galileo OS (see Section C3.3) are able to estimate their position. Depending on the Galileo OS SIS used, the Positioning Service is provided in either single-frequency or dual-frequency mode.

The Galileo OS Positioning Service, which is based on the Galileo OS Ranging Service, is interoperable with GPS positioning services. It therefore provides a direct benefit to users who are able to exploit both Galileo and GPS constellations, by increasing the number of available satellites in view.

## 1.5.3 GALILEO OS UTC TIME DETERMINATION SERVICE

GNSS satellites broadcast additional data which allow GNSS receivers to relate the GNSS time scale to international reference timescales. The precise atomic clocks in the Galileo system allow delivery to users of very accurate timing data. The OS UTC Time Determination Service provides Galileo users worldwide with direct and accurate access to the Universal Time Coordinated (UTC) reference. It provides both the integer offset between the Galileo System Time (GST) and UTC (see also section 1.6.5.2) and the fractional GST-UTC difference at nanosecond level. This allows users to time-stamp their data in UTC or local time and to precisely synchronise to UTC their clocks, which can be situated at very different locations in the world.

# 1.6 GALILEO SYSTEM OVERVIEW

The Galileo system is composed of a Core Infrastructure and a number of Service Facilities. The Core Infrastructure, in turn, comprises a Space Segment and a Ground Segment.

The Galileo Space Segment consists of a constellation of satellites transmitting navigation signals providing user access to the Galileo services. The Galileo Ground Segment consists of a ground infrastructure providing the functionality to monitor and control the satellite constellation and the generation and further dissemination of the mission data that are included in the navigation signals (i.e. the Galileo navigation message) and broadcast to the users.

The Galileo system, once fully deployed, will offer five high-performance services worldwide:

- **Open Service (OS):** Galileo open and free of user charge service set up for positioning and timing services. The OS are the only services addressed in this document.
- **Public Regulated Service (PRS):** Service restricted to government-authorised users, for sensitive applications that require a high level of service continuity.
- **High Accuracy Service:** A free access service complementing the OS, delivering high accuracy data and providing better ranging accuracy, enabling users to achieve sub-meter level positioning accuracy.
- **Commercial Authentication Service:** A service complementing the OS, providing a controlled access and authentication function to the users.
- **Search and Rescue Service (SAR):** Europe's contribution to COSPAS-SARSAT, an international satellite-based search and rescue distress alert detection system.

In the future, the Galileo Open Service will also provide Navigation Message Authentication, which allows the computation of the user position using authenticated data extracted from the navigation message. Open Service Navigation Message Authentication is not currently provided as part of the service, but test signals for Navigation Message Authentication may be broadcast without any associated Minimum Performance Level defined.

## 1.6.1 GALILEO SPACE SEGMENT

The Galileo Space Segment generates and transmits the Galileo navigation signals as specified in the Galileo OS SIS ICD (Annex A [1]).

The baseline Galileo constellation configuration is defined as a 24/3/1 Walker constellation: 24 nominal Medium Earth Orbit satellites are arranged in 3 orbital planes, with their ascending nodes uniformly distributed at intervals of 120 degrees, inclined at 56 degrees with respect to the Equator. Each orbital plane includes 8 satellites uniformly distributed within the plane, at intervals of 45 degrees of argument of latitude. The angular shift between satellites in two adjacent planes is 15 degrees. The constellation is complemented by spare satellites that can be repositioned to any given nominal slot within each orbit plane depending on maintenance or service evolution needs.

The constellation geometry repetition period corresponding to the nominal orbital parameters is approximately 10 sidereal days (corresponding to 17 orbital revolutions). This means that for any fixed Galileo user, the local satellite geometry at a given instant will repeat every 10 sidereal days, approximately.

The main reference orbit parameters of the Galileo constellation are specified in Table 1. The fully deployed constellation is further described in Annex C, while the constellation that is operational at the time of publication of this OS SDD is described in Section 3.2.

REFERENCE ORBIT PARAMETER	NOMINAL VALUE
Constellation Type	Walker 24/3/1
Orbit semi-major axis, m	29599801
Orbit eccentricity	0
Orbit inclination, deg	56.0
Argument of Perigee, deg	0.0

Table 1. Reference Orbit Parameters

## 1.6.2 GALILEO GROUND SEGMENT

The Galileo Ground Segment comprises both the Ground Control Segment and the Ground Mission Segment and it includes the following infrastructure:

- Two Galileo Control Centres (GCC), implementing ground control and ground mission capabilities at each site.
- A worldwide network of Galileo Sensor Stations (GSS), which collects and forwards Galileo SIS measurements and data to the GCCs in real time.
- A worldwide network of Galileo Uplink Stations (ULS), which distributes and uplinks the mission data to the Galileo constellation.
- A worldwide network of Telemetry, Tracking & Control stations (TTC stations), which collects and forwards telemetry data generated by the Galileo satellites, and distributes and uplinks the control commands required to maintain the Galileo satellites and constellation in nominal operational conditions.

An overview of the Galileo Ground Segment is provided in Figure 1, where only the Galileo Ground Segment functionality related to the Open Service is included.

The Galileo Ground Segment implements all functions required to:

- Generate the Galileo mission support data (e.g. satellite orbit and time synchronisation data, ionospheric correction model data and other information transmitted in the navigation signals).
- Perform the monitoring and control of all Galileo system assets (both ground and space segment).
- Interface with the Service Facilities (see Section 1.6.3), entities that are not part of the Galileo core infrastructure ground segment but nevertheless have a role in the provision of the Galileo services and are considered part of the Galileo System (e.g. Time Service Provider, Geodetic Reference Service Provider, COSPAS - SARSAT mission segment, European GNSS Service Centre).

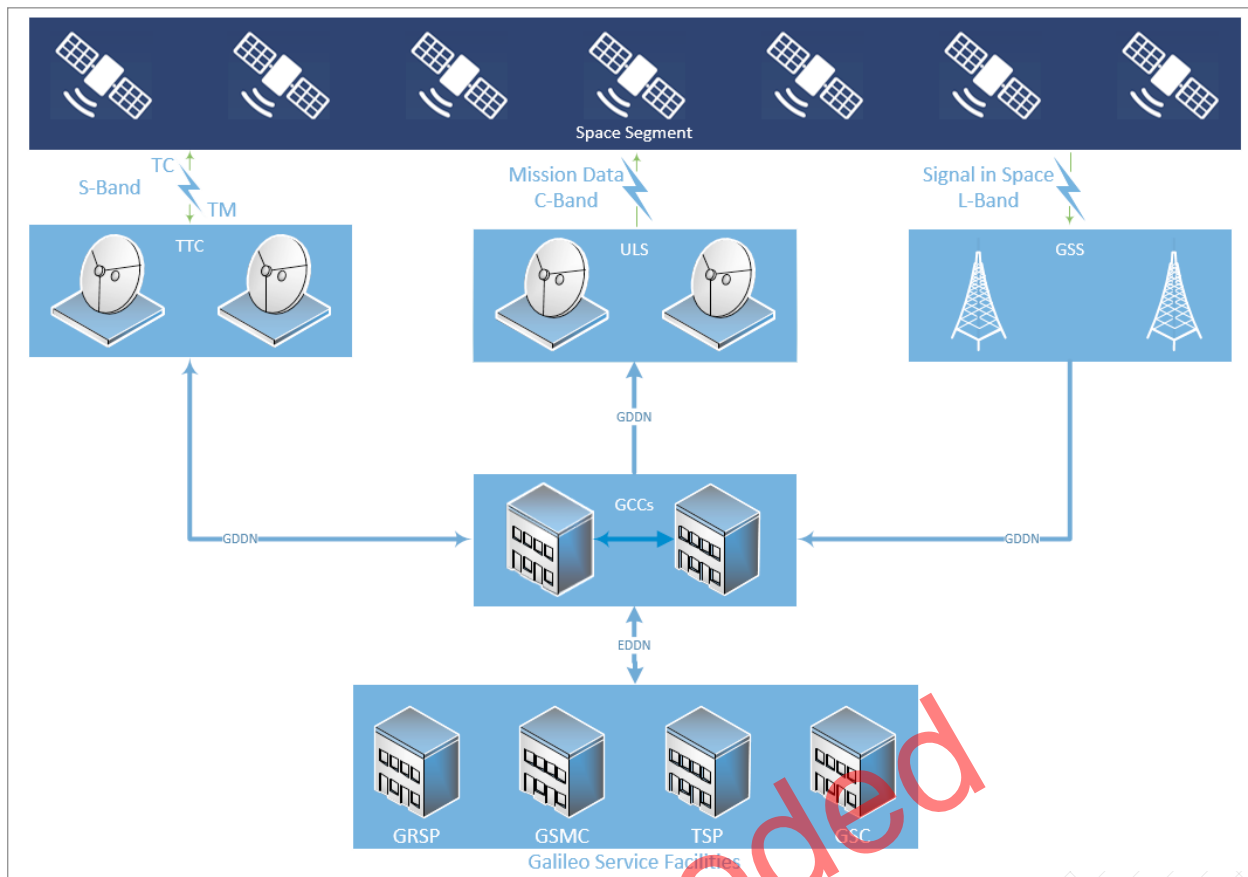


Figure 1. High level scheme of the Galileo Ground Segment Architecture.

#### 1.6.2.1. GROUND CONTROL SEGMENT

The Galileo Ground Control Segment (GCS) provides a large range of functions to support the management and control of the satellite constellation. The scope of this functionality includes control and monitoring of the satellites and payload, planning and automation functions that allow safe and correct operations to take place, and the support of payload related operations by means of TT&C links.

#### 1.6.2.2. GROUND MISSION SEGMENT

The Galileo Ground Mission Segment (GMS) determines the navigation and timing data part of the navigation messages and transmits it to the satellite via its C-Band ground stations.

The GMS architecture consists of facilities deployed in the 2 Galileo Control Centres (GCCs) plus ULS and GSS Stations deployed at remote sites located around the world. The Ground Mission Segment includes the Processing Chain, which is in charge of computing the data to be broadcast in the Galileo navigation messages.

### 1.6.3 GALILEO SERVICE FACILITIES

The Galileo Service Facilities are elements located outside the perimeter of the Galileo Core Infrastructure that support the provision of Galileo services.

The service facilities contributing to the provision of the Galileo OS are:

- The European GNSS Service Centre (GSC): GSC is the interface between the Galileo OS user community and the Galileo system (see section 1.6.4 for further information).
- The Geodetic Reference Service Provider (GRSP): This entity supports the GCC in realising the Galileo Terrestrial Reference Frame (GTRF), consistently with the international Terrestrial Reference Frame (ITRF).
- The Time Service Provider (TSP): This entity supports the GCC in the realisation of the Galileo System Time (GST) and its alignment to the Coordinated Universal Time (UTC).

- The Galileo Security Monitoring Centre (GSMC): This facility is in charge of monitoring the system security.

An additional service facility, the Galileo Reference Centre (GRC), is responsible for monitoring and assessment of the performance of the Galileo services, completely independently from the Galileo core infrastructure and its operations.

## 1.6.4 THE EUROPEAN GNSS SERVICE CENTRE (GSC): GALILEO INTERFACE WITH USERS

The European GNSS Service Centre (GSC), part of the European GNSS infrastructure, provides the single centralised ground interface between the Galileo user communities (for OS, high accuracy service and commercial authenticated service) and the Galileo system infrastructure and operator, for the provision of specific services beyond the SIS transmitted by the Galileo satellites. It is accessible through its web portal [www.gsc-europa.eu](http://www.gsc-europa.eu).

The GSC is conceived as a centre of expertise, knowledge sharing, custom performance assessment, information dissemination and support to the provision of value-added services enabled by the Galileo services. To implement these objectives, the GSC interfaces with the key elements of the Galileo ground segment, as well as with external entities. Figure 2 depicts the overall context of the GSC.

### 1.6.4.1. GSC FUNCTIONALITY

The GSC has the task of interfacing with the user communities across the entire value chain.

The GSC web portal is conceived as the one-stop-shop providing ready access to key information for user communities of Galileo OS, High Accuracy and Safety-of-Life (SoL) services.

The functionality and services covered by the GSC are:

- Helpdesk support:  
For answering general queries and incident notifications from users on Galileo SIS and specific queries from Galileo receiver and application developers on the official Galileo user documents. In addition, registered users can subscribe to be informed in real time about events affecting the Galileo services.
- Information on Galileo system status:  
Publication of Galileo almanacs and ephemeris data, of constellation status and provision of Galileo Service Notices.
- Publication of notifications to users:  
General information on the constellation and current status of the different space vehicles are published by means of Notice Advisory to Galileo Users messages (NAGUs, see section 1.6.4.1.1), which inform regularly about the system status. Users have the possibility of subscribing to the automatic notification of NAGUs via e-mail.
- Reports on the Galileo Open Service navigation key performance indicators and on the GSC performance itself are also published for the users' information.
- Electronic Library, including Programme Reference documentation and general information.
- Support to GNSS developers, including the GNSS Simulation and Testing infrastructure (GSTI).
- Interface with other GNSS Service Providers.
- Galileo user satisfaction monitoring, including customised performance assessment, reporting and forecasts for specific communities, and support to the Galileo services development for each community or domain.

#### 1.6.4.1.1. NOTIFICATIONS TO USERS (NAGUS)

The GSC is responsible for the publication of Notice Advisory to Galileo Users (NAGU) messages. NAGUs are used to notify Galileo users about the SIS status of all satellites in the Galileo constellation. Different kinds of NAGUs are issued depending on the specific event to be communicated, related to either changes in the constellation (commissioned and decommissioned

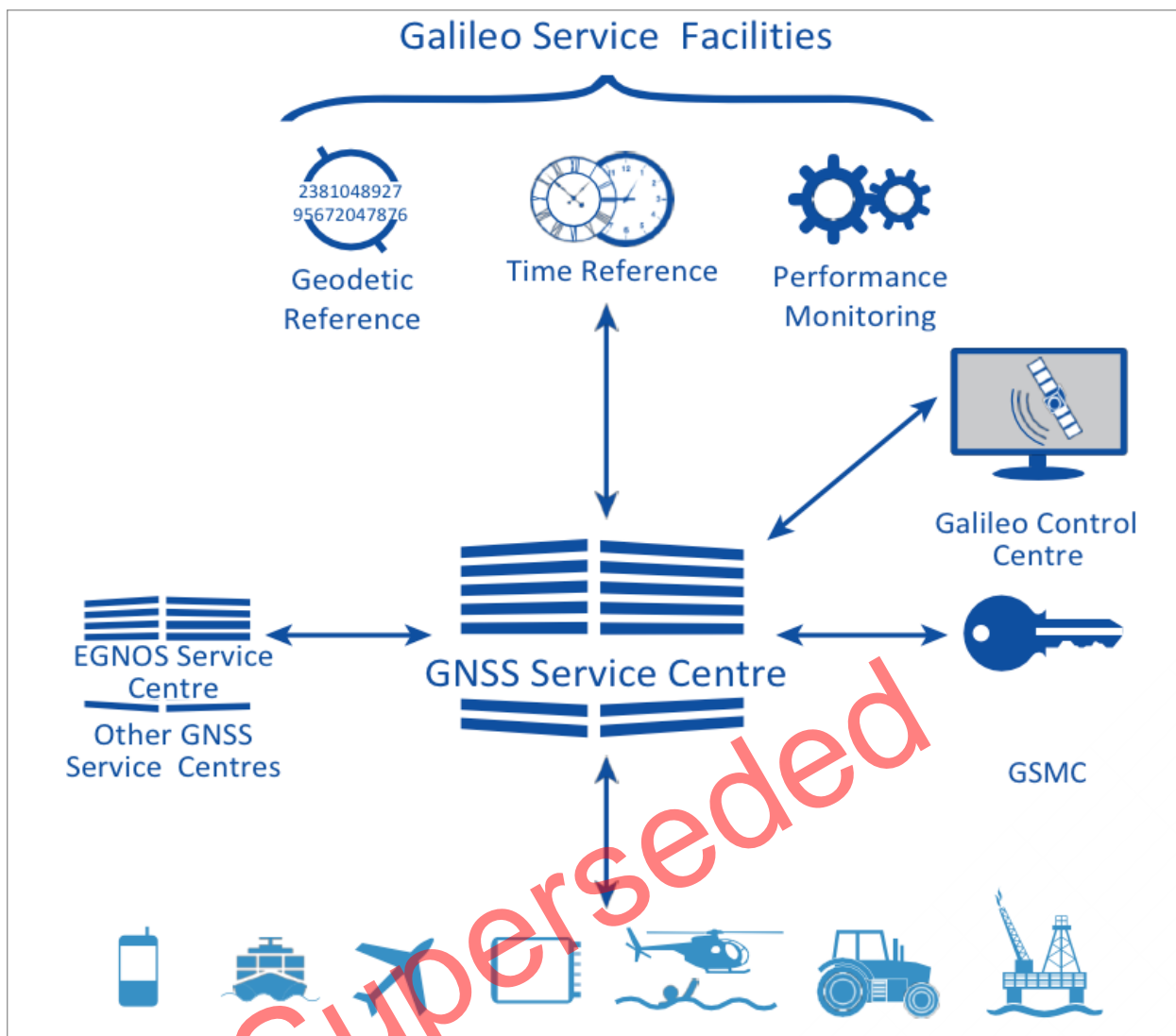


Figure 2. Overall context of the GSC

satellites, for example) or to occurrence and recovery of (planned and unplanned) outages of SIS.

Examples of planned events that are anticipated through the publication of a specific NAGU are satellite manoeuvres and maintenance activities, declaration of a satellite entering into service, recovery from outages. Examples of unplanned events that are notified through the publication of a specific NAGU are satellite failure, information about short outages already recovered, unscheduled outages of SIS of an undefined duration.

The description of the structure and content of the NAGUs is provided in Annex E. This information, together with the list of active and archived NAGUs can be also found in the GSC web page, [www.gsc-europa.eu](http://www.gsc-europa.eu), under "System Status".

Specific MPLs apply for the timely publication of NAGUs (see section 3.6.1).

### 1.6.5 GALILEO TIME AND GEODETIC REFERENCE FRAMES

The Galileo system establishes its independent terrestrial reference frame and system time scale. The satellite positions and satellite clock offsets encoded in the navigation data are referenced to these Galileo time and terrestrial internal references. Without additional processing, the navigation solution computed by a Galileo OS receiver (using the mathematical algorithms described in the SIS-ICD) provides the receiver's position and time offset referenced to these internal references.

The Galileo system terrestrial and time references are:

- Galileo Terrestrial Reference Frame (GTRF): the Galileo spatial reference frame

The instantaneous satellite positions derived from the data provided in the OS SIS and using the algorithm defined in the OS SIS ICD (Annex A [1]) are referenced to the GTRF. The GTRF is specified to always be in line with the international terrestrial reference frame, as defined by the international Earth Rotation and Reference Systems Service (IERS). The GTRF specification is provided in section 1.6.5.1.

- Galileo System Time (GST): the Galileo time and frequency reference

The instantaneous satellite clock parameters derived from the data provided in the OS SIS and using the algorithm defined in the OS SIS ICD (Annex A [1]) are referenced to the Galileo System Time. The GST is aligned with the International Atomic Time (TAI) and the required parameters to transform it to UTC are transmitted in the navigation message, as explained in section 1.6.5.2.

#### 1.6.5.1. GALILEO TERRESTRIAL REFERENCE FRAME

The Galileo Terrestrial Reference Frame is the independent realisation of the international Terrestrial Reference System based on the estimated coordinates of each one of the Galileo Sensor Station (GSS) sites.

The determination of the GSS positions is based on global free network adjustment and the precise network solution thus obtained is aligned to the international Terrestrial Reference Frame. For this purpose, a significant number of ITRF stations co-located or non-co-located with GSSs are part of the network of stations operated by the GRSP.

The GTRF is a highly accurate realisation of the ITRS. At any time, the alignment between the GTRF and the latest physical realisation of the ITRF is such that the difference between the ITRF and the GTRF coordinates of the ITRF stations/markers used in the realisation of the GTRF is less than 3 cm ( $2\sigma$ ).

The Galileo system uses the geodetic input information to produce navigation data (e.g. satellite ephemeris) referenced to the GTRF. Accordingly, the user position coordinates derived from Galileo position solutions are referenced to GTRF. Due to the good alignment of GTRF to ITRF both reference frames are understood to be equivalent in the frame of this document. The GTRF is regularly aligned if new ITRF realisations are published.

To obtain the position in any reference frame different from ITRF, Galileo OS user equipment needs to apply the appropriate valid transformation parameters between the latest ITRF and the desired reference frame. This transformation is under full control and responsibility of the Galileo OS user.

Concerning the interoperability between GPS and Galileo, the GPS terrestrial reference frame and the GTRF are both realisations of the ITRF. Therefore, for most OS applications, a high level of interoperability is provided between the spatial positions obtained with GPS and those obtained with Galileo, without further activity by the user equipment.

#### 1.6.5.2. GALILEO SYSTEM TIME


The Galileo System Time is a continuous timescale based on the definition of the second (according to the international System of Units, SI) whose origin/reference epoch GST(T0) is defined as 13 seconds before 1999-08-22 00:00:00 UTC. UTC is the time scale endorsed by the 15th General Conference of Weights and Measures for worldwide time coordination and dissemination. It is the international time metrological standard and it is maintained, coordinated and disseminated by the BIPM.

UTC is defined as an atomic timescale (time interval is consistent with the SI definition of the second), but unlike GST, it is steered towards UT timescale (which is not based on atomic standards but on the Earth rotation period).

The time synchronisation information disseminated in the Galileo SIS (e.g. satellite clock offsets) is referenced to GST. This information allows the Galileo OS users to estimate their local time referenced to the GST realisation computed by the OS receiver.

In order to better support timing applications based on UTC, the Galileo OS data message includes additional parameters which enable the Galileo OS users to obtain a realisation of the UTC time by applying a correction to the GST (further details are provided in Annex C.4.6).

Superseded

A detailed illustration of a Galileo satellite in orbit. The satellite is shown from a perspective that highlights its large, rectangular solar panel arrays, which are covered in a grid of dark solar cells. The satellite's main body is complex, with various instruments and antennas visible. It is positioned in a curved orbital path against the backdrop of a star-filled space. In the bottom left corner, the curved horizon of the Earth is visible, showing a mix of green land and blue oceans. A large, semi-transparent red watermark with the word 'Superseded' is oriented diagonally across the center of the image, partially obscuring the satellite and the text.

## SECTION 2: GALILEO OPEN SERVICE SIS CHARACTERISTICS AND MINIMUM USAGE ASSUMPTIONS

This section starts with a short description of the Galileo OS SIS interface characteristics, which is provided for information purposes. The reference document for details of the Galileo OS SIS Interface characteristics is the OS SIS ICD (Annex A [1]). In the event of conflict between the OS SIS interface characteristics described in this document and the OS SIS ICD, the latter shall prevail.

A description is then provided of the different MPLs, along with the minimum usage assumptions for the users of the Galileo OS.

## 2.1 OS SIS INTERFACE CONTROL DOCUMENT REQUIREMENTS

The OS SIS complies with the technical requirements related to the interface between the Space Segment and the OS receivers as established by the OS SIS Interface Control Document (ICD) (Annex A [1]).

## 2.2 OVERVIEW OF OS SIS INTERFACE CHARACTERISTICS

### 2.2.1 GALILEO OS SIS RF CHARACTERISTICS

Galileo transmits several signals and codes on four different carrier frequencies within the 1.1 to 1.6 GHz band, namely:

- E1, centred at 1575.42 MHz;
- E5a and E5b, at 1176.45 and 1207.14 MHz respectively, multiplexed together through an AltBOC scheme and transmitted at the E5 carrier frequency centred at 1191.795 MHz;
- E6, centred at 1287.75 MHz.

A complete representation of the Galileo signal baseline is provided in Figure 3.

The Galileo SF OS is provided by each of the three signals: E1 E5a and E5b, whereas the Galileo DF OS is provided by each of the following signal combinations broadcast by the same satellite:

- E1 and E5a.
- E1 and E5b.

The E1 OS signal comprises a pair of components modulated with the CBOC(6,1,1/11) scheme:

- a data component (E1-B), carrying the I/NAV navigation message (see section 2.2.2) with a data rate of 125 bps and a symbol rate (after FEC) of 250 sps, modulated with CBOC(6,1,1/11,+);

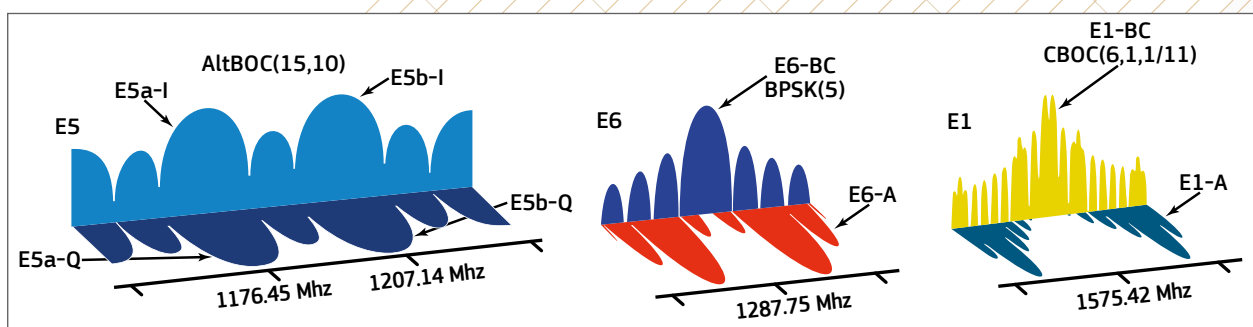


Figure 3. Signals transmitted by Galileo satellites

- a data-less component (E1-C), modulated with a CBOC(6,1,1/11,-).

The E5 signal is made of four components multiplexed together through an AltBOC(15,10) scheme:

- a pair of components on the E5a carrier:
- a data component (E5a-I), carrying the F/NAV navigation with a data rate of 25 bps and a symbol rate of 50 sps;
- a data-less component (E5a-Q);
- a pair of components on the E5b carrier:
- a data component (E5b-I), carrying the I/NAV navigation message with a data rate of 125 bps and a symbol rate of 250 sps;
- a data-less component (E5b-Q).

All components of E5a and E5b are generated coherently, which allows them to be processed together for increased accuracy and redundancy, when required.

## 2.2.2 GALILEO OS SIS NAV MESSAGE CHARACTERISTICS

The Galileo OS is provided through two different message types (see Table 2): the F/NAV and the I/NAV navigation messages.

MESSAGE TYPE	COMPONENT
F/NAV	E5a-I
I/NAV	E5b-I and E1-B

Table 2. Mapping of Message types to Signal Components

The complete navigation message data are transmitted on each data component as a sequence of frames. A frame is composed of several sub-frames, and a sub-frame in turn is composed of several pages. The page is the basic structure for building the navigation messages.

Each navigation message contains all the necessary parameters and information that enable the OS Users to access the services. This includes:

- the time parameters and clock corrections, needed to compute satellite clock offsets and time conversions;
- the ephemeris parameters, needed to compute the satellite coordinates;

- the service parameters, with satellite health information;
- the ionospheric parameters model, needed for single-frequency receivers;
- the almanacs, allowing less precise computation of the position of all satellites in the constellation to facilitate the initial acquisition of the signals by the receiver.

The purpose, structure and content with full details concerning the Galileo OS SIS Navigation Message can be found in the Galileo OS SIS ICD (Annex A [1]).

In the context of this document, the term "navigation message" refers to a sub-frame (50 seconds for F/NAV and 30 seconds for I/NAV), which contains ephemeris and clock and ionospheric corrections or SIS status information, that is, Page Type 1 to 4 for the F/NAV and Word Type 1 to 6 for the I/NAV, unless otherwise specified.

### 2.2.2.1 THE CYCLIC REDUNDANCY CHECK IN GALILEO NAVIGATION MESSAGE

To detect corruption of the received data, a checksum is used by the Galileo navigation message, employing a CRC technique. The detailed description of this checksum is provided in the OS SIS ICD (Annex A [1]).

The CRC is not used to indicate any problem at satellite level, on the transmitter side. The CRC checksum is related exclusively to the errorless reception of the transmitted bits, i.e. to the transmission channel, not to the correctness of the structure or the contents of the message as transmitted by the Galileo system. The CRC within the navigation message of Galileo is therefore not involved in the definition of the SIS Status.

If the CRC checksum is not passed successfully, the respective data must be rejected and no determination of the SIS Status is possible. Once a navigation message is received with a successful CRC, the user can then proceed to the SIS Status determination, as described in the next section, and eventually to the utilisation of such SIS.

## 2.3 OVERVIEW OF GALILEO OS PERFORMANCE CHARACTERISTICS

The Galileo OS performance characteristics are the following: Status, Accuracy and Availability.

### 2.3.1 GALILEO OS SIS STATUS

Users of the Galileo OS can obtain information about the OS SIS Status, i.e. about the operational status of the OS SIS broadcast by each one of the Galileo satellites, through the signals themselves, when transmitted.

The Galileo OS SIS Status can take one of the following three values:

- Healthy,
- Unhealthy,
- Marginal.

The meaning of the three possible values of the SIS Status is the following:

- SIS “Healthy”: The SIS is expected to meet the Minimum Performance Level<sup>1</sup>.
- SIS “Unhealthy”: The SIS is out of service or under test.
- SIS “Marginal”: The SIS is in neither of the two previous states.

The Galileo OS Minimum Performance Levels reported in the Galileo OS SDD refer exclusively to Healthy SIS. No MPL is defined for Unhealthy or Marginal SIS. Moreover, a navigation solution obtained with Galileo SIS is expected to meet the Minimum Performance Levels reported in the Galileo OS SDD only if receivers comply with the assumptions reported in Section 2.4, including the use of navigation parameters within their broadcast period (see also footnote 8).

1..... This assertion does not apply to the Minimum Performance Level for the provision of the Galileo-GPS System Time Offset (GGTO, see section 3.5.1.1). Healthy SIS can broadcast parameters that indicate a non-valid GGTO (see (Annex A [1]) for more details about the dummy value of the GGTO parameters).

#### 2.3.1.1. SIS STATUS DISSEMINATION

The status of each Galileo signal involved in the provision of OS is determined by the SIS Status information embedded in the navigation message or by the presence of a specific “dummy message” that may replace the standard one (see section 2.3.1.2).

Users are also notified off-line about the SIS status of the satellites in the Galileo constellation through the publication of the Notice Advisory to Galileo Users, by the GSC (see section 1.6.4).

#### 2.3.1.2. DUMMY NAVIGATION MESSAGE

Dummy pages are defined in the Galileo OS SIS ICD (Annex A [1]) (Page/Word Types 63 for F/NAV and I/NAV, respectively). Such dummy pages, if transmitted, replace all the sub-frames containing ephemeris and clock corrections of the navigation message, which is then defined as dummy navigation message. A dummy navigation message indicates an Unhealthy SIS. Therefore, as soon as a dummy page, i.e. Page/Word Types 63, is decoded by a receiver, the respective SIS must be considered Unhealthy.

Once the transmission of the dummy message terminates and normal transmission is recovered, users must follow the appropriate procedure to check the SIS Status, as described in the next sections, before starting to reuse the SIS.

Note that in the case of Dual-Frequency (DF) users, a dummy navigation message on either one of the frequencies implies that the DF SIS is not Healthy (see also section 2.3.1.4 <sup>2</sup>).

#### 2.3.1.3. SIS STATUS FLAGS

The status of the Signal-In-Space is encoded within the navigation message through three SIS Status Flags:

- The Signal Health Status (SHS) flag.
- The Data Validity Status (DVS) flag.
- The Signal-In-Space Accuracy (SISA) value.

Full details concerning the position of the Galileo SIS Status flag within the Galileo SIS Navigation Message can be found in the Galileo OS SIS ICD (Annex A [1]).

2..... The navigation message, specifically the I/NAV, transmitted on E1 and E5b, has been designed to include another type of page: the Alert Pages (see OS SIS ICD, Annex A [1] for a detailed definition). The transmission of Alert Pages is a capability that the Galileo system is currently not exploiting.

## Signal Health Status (SHS)

The SHS flag is contained in the navigation data and the almanac messages of each Galileo OS signal (E1, E5a or E5b). For E1 and E5b, the SHS flags are included in the I/NAV navigation data stream. For E5a, the SHS flag is included in the F/NAV navigation data stream.

The SHS flag to be used is the one broadcast in the navigation data transmitted by the satellite whose SIS is being used.

The SHS flags broadcast as part of the almanac data are provided for convenience in support of satellite acquisition but shall not be used operationally to determine the SIS Status.

The SHS flag can be raised by the system at any moment<sup>3</sup>. The SHS flags can take the values defined in the OS SIS ICD (Annex A [1]), which are recalled for convenience in Table 3.

SIGNAL HEALTH STATUS (SHS)	DEFINITION
0	Signal OK
1	Signal out of service
2	Signal will be out of service
3	Signal component currently in Test

Table 3. Signal Health Status Bit Values

## Data Validity Status (DVS)

For each Galileo OS signal (E1, E5a or E5b), the DVS flag is contained in the navigation data. For E1 and E5b, the DVS flags are included in the I/NAV navigation data stream. For E5a, the DVS flag is included in the F/NAV navigation data stream. The flag can assume the values defined in the OS SIS ICD (Annex A [1]), which are recalled for convenience in Table 4.

The DVS can be triggered independent of navigation message refresh and users shall expect that its value can change at any time.

DATA VALIDITY STATUS (DVS)	DEFINITION
0	Navigation data valid
1	Working without guarantee (WWG)

Table 4. Data Validity Status Bit Values

## Signal-In-Space Accuracy (SISA)

For E1 and E5b, the SISA index is contained in the I/NAV navigation data stream. For E5a, the SISA index is contained in the F/NAV navigation data stream.

As described in the OS SIS ICD, the SISA is a prediction of the minimum standard deviation ( $1\sigma$ ) of the unbiased Gaussian distribution which overbounds the Signal-in-Space Error (SISE, see Section 2.3.2.1) predictable distribution for all possible user locations within the satellite coverage area. The SISA parameter can assume 255 values. Nevertheless, when the SISA is used as one of the means for determining the SIS Status, it must be considered as a binary indicator, with its only meaningful values being “No Accuracy Prediction Available” (that is NAPA, when  $SISA=255$ ) or “not NAPA” (when  $SISA \neq 255$ ). Note that those SISA values described in the OS SIS ICD (Annex A [1]) as Spare (from 126 to 254) are to be considered as “not NAPA”

The SISA index values relevant to the assessment of the SIS Status, as defined in the OS SIS ICD (Annex A [1]), are recalled for convenience in Table 5.

SISA INDEX	SISA VALUE
255	No Accuracy Prediction Available (NAPA)
0.....254	Not NAPA

Table 5. SISA Index values relevant to the assessment of the SIS Status

### 2.3.1.4. MAPPING BETWEEN SIS STATUS FLAGS AND SIS STATUS

The mapping between the values of the SIS Status Flags, presented in section 2.3.1.3, and the three values of the SIS Status is provided in Table 6. In order to determine the Status for a specific SIS broadcast by a Galileo satellite, the user must ensure that the navigation message has been properly received, i.e. it has successfully passed the CRC check (see section 2.2.2.1).

The first condition to be fulfilled by the navigation message in order for the user to proceed with the determination of the SIS Status is that it must not be a dummy message. As explained in section 2.3.1.2, in case of dummy message the respective SIS must be considered Unhealthy.

If the message is not dummy, the user can proceed with checking the other conditions to determine the SIS Status as specified in Table 6. The order in which the flags are checked by a receiver on receipt of a non-dummy navigation message is arbitrary and up to the manufacturer. The value of each flag can be read (and taken into account) independently from the value of the other flags. An

<sup>3</sup>..... The Time To Alert between the occurrence of an event and the setting of the SHS is under definition.

SIS STATUS	DUMMY MESSAGE	SIS FLAGS		
		SHS	DVS	SISA
Healthy	No	OK	NDV	not NAPA
Unhealthy	No	Out of Service	Any Value	Any Value
	No	In Test	Any Value	Any Value
	Yes	N/A	N/A	N/A
Marginal	No	Ok	WWG	Any Value
	No	Ok	Any Value	NAPA
	No	Will be out of Service	Any Value	Any Value

Table 6. Galileo Open Service SIS Status vs SIS Status Flags

example of a possible decision tree for the determination of the SIS Status is provided in Figure 4.

As an example of receiver operations, in section 2.3.1.3 it is explained that DVS flag equal to WWG implies that the respective SIS cannot be considered Healthy but, depending on the value of the other flags, only Marginal.

This means that the SIS might not meet the MPLs defined in this document. As soon as receivers detect that the DVS value has been set back to 0 and that, taking into account the other relevant flags, the SIS Status is back to Healthy, they will have to retrieve the most recently broadcast navigation data in order to use such SIS.

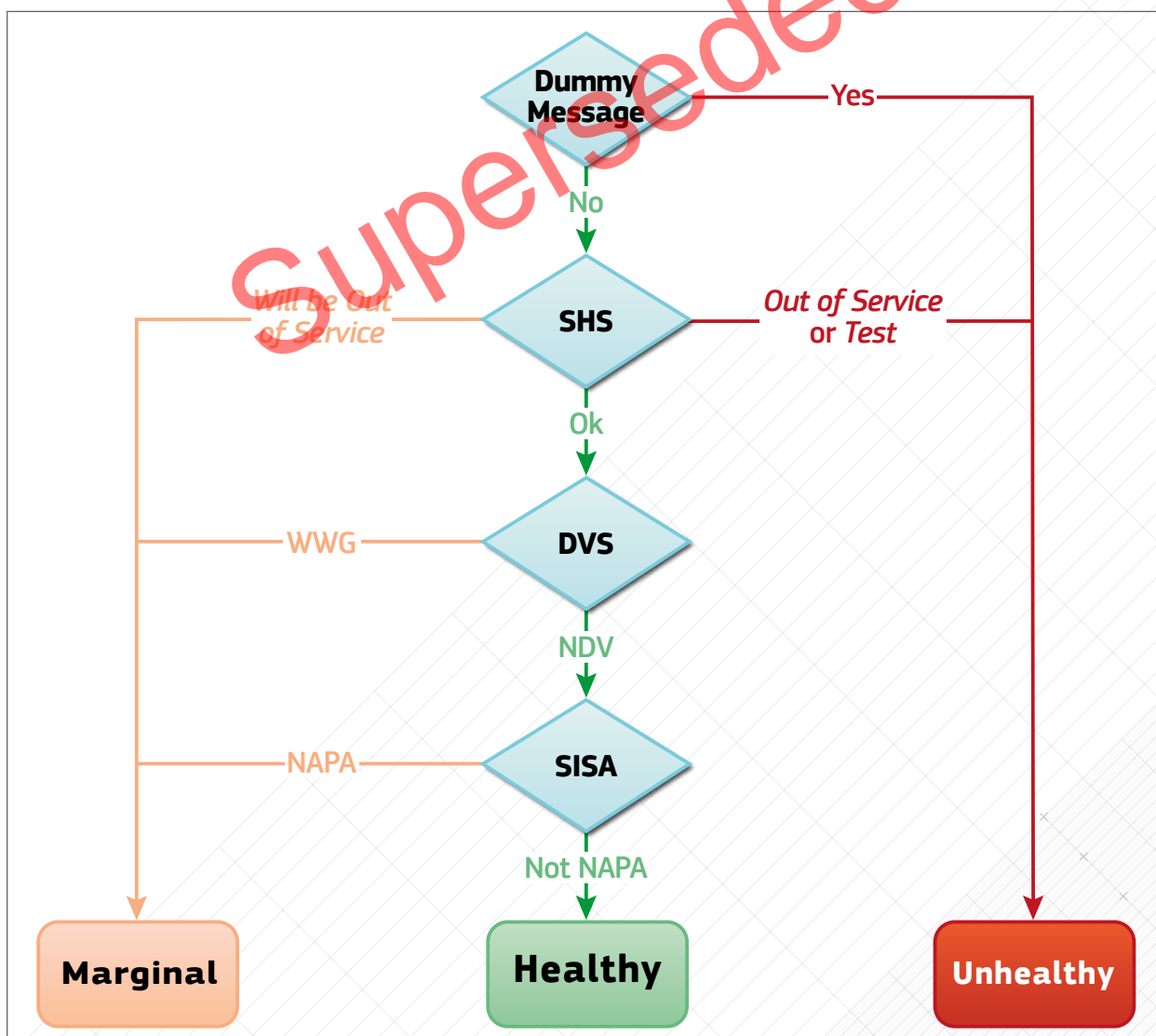


Figure 4. Example of Decision Tree for the Determination of the Status of broadcast SIS.

This means that all parameters to be used by a receiver have to be retrieved after the SIS is (back to) Healthy in order to ensure that the MPLs are expected to be met.

Note also that the value of SIS Status flags applies to the whole sub-frame they belong to. As an example, the DVS flag in the I/NAV message is located in Word Type 5 but its value is applicable also to the content of the Word Type 1, 2, 3 and 4.

Depending on the service to be used, Single-Frequency (SF) or Dual-Frequency (DF), Users will have to check the value of the various flags on different SIS. Table 7 shows the summary of the SIS Status Flags to be checked by the different Galileo OS users for both SF and DF services.

USERS		F/NAV			I/NAV				
		E5a <sub>HS</sub>	E5a <sub>DVS</sub>	SISA(E1,E5a)	E1B <sub>HS</sub>	E1B <sub>DVS</sub>	E5b <sub>HS</sub>	E5b <sub>DVS</sub>	SISA(E1,E5b)
SINGLE FREQUENCY	E1				X	X			X
	E5a	X	X	X					
	E5b						X	X	X
DOUBLE FREQUENCY	E1/E5a	X	X	X	X	X			
	E1/E5b				X	X	X	X	X

Table 7. Summary of SIS flags to be checked by the different Galileo OS users to compute the Status of Signals-In-Space

satellite position and time, projected to the user-satellite direction. The SISE is the system contribution to the GNSS error budgets to the User Equivalent Range Error (UERE), and contains all effects originating from and/or controlled by the Galileo system, while user local effects as well as atmospheric effects and SIS propagation effects (ionospheric/tropospheric) are not considered.

Since the instantaneous SISE depends on the user-satellite direction i.e. on the user position, the Global Average SISE is defined as the root-mean-square of the instantaneous SISE across the coverage area of the Galileo satellite considered. In turn, the constellation average of the instantaneous SISE is defined as the root-mean square of the “global average” as defined above, across the Galileo constellation at a given time.

The Galileo OS Ranging Accuracy (respectively Galileo OS Ranging Accuracy over all satellites) is defined as the 95th percentile of the time series of the global average SISE (respectively of the constellation average SISE). They are only measured for time periods during which the transmitted SIS was healthy. Galileo OS Ranging Accuracy (and therefore Galileo OS Ranging Accuracy over all satellites) are evaluated over all age of data (AOD<sup>4</sup>) values, i.e. the SISE time series will consider the navigation message at the age of data when it was observed. Expected ranging accuracies for different values of AOD are provided in Annex D.

### 2.3.2.2. GALILEO OS RANGING RATE ACCURACY

*The Galileo SIS Ranging Rate Accuracy will be defined in a future issue of the OS SDD.*

## 2.3.2 GALILEO OS ACCURACY: RANGING SERVICE

The Galileo OS Ranging Service Accuracy performance is based on the following two parameters:

- Galileo OS Ranging Accuracy
- Galileo OS Ranging Rate Accuracy.

### 2.3.2.1. GALILEO OS RANGING ACCURACY

The Galileo OS Ranging Accuracy is defined as a statistical measure of the Galileo SIS Ranging Error (SISE). The SISE is defined as the instantaneous difference between the position and time of a Galileo satellite as broadcast by the Galileo OS navigation message and the true

## 2.3.3 GALILEO OS ACCURACY: TIME DISSEMINATION SERVICE

The Galileo OS provides means for users to determine UTC by estimation of the GST-UTC difference using the parameters transmitted in the Galileo OS SIS. This is done by first estimating the local offset from GST, and secondly estimating the offset of GST with respect to UTC applying the GST-to-UTC conversion provided in the Galileo OS navigation data (see Annex A [1]). The accuracy in the UTC estimation, which is called the Galileo

<sup>4</sup>..... The Age of Data is the elapsed time since the generation of the navigation message data.

UTC Time Determination Accuracy, depends therefore on both the instantaneous GST determination error and on the error in the broadcast GST-UTC conversion parameters. This second component is defined as the Galileo SIS UTC Time Dissemination Accuracy.

The Galileo OS UTC Time Dissemination Accuracy performance is characterised by:

- Galileo SIS UTC Time Dissemination Accuracy.
- Galileo SIS UTC Frequency Dissemination Accuracy.

As for all performance parameters included in the OS SDD, the UTC Time Dissemination Accuracy and the UTC Time Determination Accuracy do not include effects that are not under the control of the Galileo operator, such as user local contributions depending on the receivers or due to atmospheric effects, which have to be accounted for to assess the total uncertainty in the UTC estimation experienced by the user. Figure 5 shows the various components of the total uncertainty in the estimation of the UTC Time.

### 2.3.3.1. GALILEO SIS UTC TIME DISSEMINATION ACCURACY

Galileo SIS UTC Time Dissemination Accuracy is the SIS component of the overall user's UTC Time Determination, which is driven by the accuracy of the broadcast GST-UTC parameters.

Galileo SIS UTC Time Dissemination Accuracy is defined as the 95th percentile of the broadcast GST-UTC conversion parameters error.

### 2.3.3.2. GALILEO SIS UTC FREQUENCY DISSEMINATION ACCURACY

The Galileo SIS UTC Frequency Dissemination Accuracy, defined on the basis of the derivative of the Galileo SIS UTC Time Dissemination Accuracy, is the major contribution to the UTC frequency transfer accuracy. Galileo SIS UTC Frequency Dissemination Accuracy is defined as the 95th percentile of the first derivative of the broadcast GST-UTC conversion parameters error, i.e. the normalised frequency offset relative to UTC.

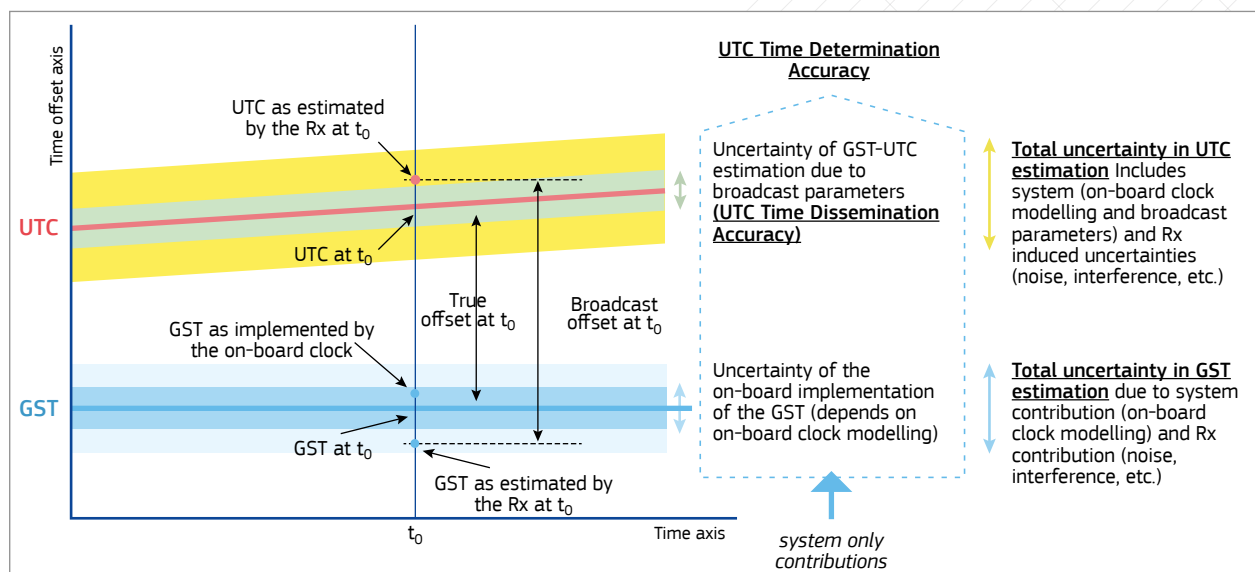


Figure 5. Graphical representation of the various components of the total uncertainty in the estimation of the UTC Time.

## 2.3.4 GALILEO OS AVAILABILITY

In the computation of all the Galileo OS availability Minimum Performance Levels, both planned and unplanned outages are included. Outages comprise the time intervals when SIS is not broadcast.

The availability performance of the Galileo OS comprises:

### 2.3.4.1. PER-SLOT AVAILABILITY OF OS SIS

Per-Slot Availability of OS SIS is defined as the average availability of Healthy SIS at any slot of the Galileo satellite constellation<sup>5</sup>. The Per-Slot Availability is provided as normalised annual value.

### 2.3.4.2. AVAILABILITY OF THE GALILEO OS UTC TIME DISSEMINATION SERVICE

The Availability of the Galileo OS UTC Time Dissemination Service is computed at any user location as the percentage of time when a user is provided with a healthy SIS, either single-frequency (E1, E5a, E5b) or dual-frequency (E1/E5a, E1/E5b), allowing UTC time estimation. The Minimum Performance Level for the Availability of Galileo OS UTC Time Dissemination Service is specified for the worst user location within the service coverage (see section C3 for the definition of service coverage). It is provided as a monthly value.

### 2.3.4.3. AVAILABILITY OF THE GALILEO OS POSITION DILUTION OF PRECISION (PDOP)

The Availability of PDOP is computed at any user location as the percentage of time at least 4 Galileo satellites are visible, above a minimum elevation of 5 degrees, transmitting healthy SIS and with a PDOP  $\leq 6$ . The availability of global PDOP is specified for the average user location<sup>6</sup>, within the service coverage, i.e. computed as the average over all user locations<sup>6</sup>. It is provided as a monthly value.

### 2.3.4.4. AVAILABILITY OF THE GALILEO OS DF AND SF POSITIONING SERVICE

The availability of PDOP (section 3.4.3) and the OS SIS ranging accuracy (section 3.3.1) determine the availability of Galileo OS DF and SF Positioning Service. This MPL is provided as a monthly value.

At any user location, the availability of DF and SF Positioning service for OS is computed as the percentage of time that the DF and SF horizontal and vertical positioning error is less than or equal to a specific threshold at 95%, considering only SIS error contributions and only healthy Galileo SIS. The Minimum Performance Level for availability of the Galileo positioning service is specified both for the average user location (AUL) within the service coverage area, i.e. computed as the average over all user locations, and for the worst user location (WUL) within the service coverage area (see section C3 for the definition of service coverage).

### 2.3.4.5. AVAILABILITY OF THE GALILEO OS UTC TIME DETERMINATION SERVICE

The Availability of UTC Time Determination service for OS is computed at any user location as the percentage of time that the UTC Time Determination error is less than or equal to a specific threshold at 95%, considering only SIS error contributions and only healthy Galileo SIS, for users at a known location. The Minimum Performance Level for the availability of Galileo UTC Time Determination Service is specified for the average user location within the service coverage (AUL), i.e. computed as the average over all user locations within the service coverage (see section C3 for the definition of service coverage). It is provided as a monthly value.

5..... The Galileo constellation is currently under deployment. The up-to-date status of the Galileo constellation is available through the European GNSS Service Centre (GSC) webpage at <http://www.gsc-europa.eu/system-status/Constellation-Information>

6..... Expected values for the availability of the Galileo OS PDOP for WUL are provided in Annex D

## 2.4 USAGE ASSUMPTIONS FOR OPEN SERVICE PERFORMANCE

The MPLs contained in this OS SDD are conditioned upon certain assumptions regarding the use of the OS SIS. Those assumptions are as follows.

### 2.4.1 OS USER RECEIVERS

This OS SDD assumes that the Galileo OS user receiver complies with the technical requirements related to the interface between the Space Segment and Galileo OS receivers as established by the Galileo OS SIS ICD (Annex A [1]). The use of aiding sensors or systems is not considered.

For each frequency or pair of frequencies used, it is assumed that the user receiver is capable of tracking the respective OS SIS (compliant to the SIS ICD (Annex A [1])) from all Galileo satellites in view above a masking angle of 5 degrees over the local horizon, and with the receiver operating within the Galileo Service Volume (as defined in section C3.3). The user has unobstructed visibility of the sky above this mask angle. As detailed in section 2.4.3, any error source related to the user receiver is not accounted for in the definition of the MPL.

It is also assumed that the user receiver uses, as described in section 5.1 of the OS SIS ICD (Annex A [1]), up-to-date ephemeris and clock data for all satellites. More specifically, receivers must retrieve the values of navigation parameters relevant to the type of navigation solution to be computed from the most recent navigation data set broadcast on a Healthy SIS by the Galileo system after the start of the current receiver operation. The performance resulting from the usage of any other set of parameters, including reduced clock and ephemeris data, is not expected to meet the Minimum Performance Level.

The navigation solution is expected to meet the Minimum Performance Levels only if receivers do not use navigation parameters beyond their broadcast period. The maximum nominal broadcast period of a healthy navigation message data set is currently 4 hours <sup>7</sup>.

It is underlined that Galileo receivers, like most GNSS receivers, can increase navigation performance by implementing fault detection and isolation algorithms, for example by using algorithms based on the consistency of redundant pseudorange data sets (such as Receiver Autonomous Integrity Monitoring (RAIM) algorithms).

#### 2.4.1.1. USAGE OF PARAMETERS IDENTIFIED BY AN ISSUE OF DATA

As defined in the OS SIS ICD, (Annex A [1]), the navigation parameters are disseminated in data batches, each identified by an Issue of Data (IOD) value. The identification of each batch by an IOD value enables:

- the users to distinguish the data in different batches received from each satellite;
- the user receiver to compute the full batch of data even if it misses some pages or starts receiving the data somewhere during the transmission.

Two independent IODs are defined for:

- the ephemeris, satellite clock correction parameters and SISA;
- the almanac.

To compute position and clock corrections, receivers must use, for each satellite, IOD-tagged parameters corresponding to the same IOD Value. Moreover, these parameters must be retrieved from the most recent navigation data set broadcast on a Healthy SIS by the Galileo satellite after the start of the current receiver operation. These are the two conditions regarding the IOD-tagged parameters under which the navigation solution is expected to meet the Minimum Performance Level. The utilisation of parameters identified by different IOD Values from a single satellite is not recommended and the resulting performance is not expected to meet the Minimum Performance Level.

<sup>7</sup>..... This time interval might be modified in the future. A procedure is described in Annex C to estimate the age of ephemeris as prediction time from reference Time of Ephemeris (t-t0e). Applying this algorithm, users are able to compare the age of the navigation parameters they have available with the maximum nominal broadcast period of a healthy navigation message data set.

Galileo satellites are not expected to all transmit the same IOD. For positioning, users can combine SIS from different satellites with different IOD Values provided that the navigation parameters derived from each satellite are tagged by a unique IOD Value.

It is relevant to note that IOD Values are not necessarily incremented in steps of one and that an IOD with higher value does not necessarily mean that it tags more recent data. The only valid comparison between IOD Values is whether they are equal or not.

Concerning the parameters not tagged by an IOD, i.e. the BGD, the ionospheric corrections, the GST-UTC and GST-GPS conversion parameters, the DVS and the SHS flags, as stated in section 2.4.1, receivers must retrieve their values (for those parameters relevant to the type of navigation solution to be computed<sup>8</sup>) from the most recent navigation data set broadcast on a Healthy SIS by the Galileo system after the start of the current receiver operation. This is the condition regarding the parameters not tagged by an IOD under which the navigation solution is expected to meet the Minimum Performance Level.

The satellite specific parameters (BGD, DVS, SHS) have to be obtained separately from each satellite and for each frequency while system parameters (ionospheric corrections, GST-UTC and GST-GPS conversion parameters) can be obtained from any Healthy SIS.

## 2.4.2 LIMITATIONS ON OS SIS STATUS

This OS SDD assumes that a Galileo receiver will only use OS SIS whose Status is indicated as Healthy. This OS SDD explicitly assumes that a Galileo receiver will not make use of an OS SIS whose health status is indicated as either Marginal or Unhealthy.

### 2.4.2.1. PRIORITY OF BROADCAST OS SIS STATUS INFORMATION

As described in section 2.3.1, for each Galileo OS signal (E1, E5a, E5b), the SHS flag is contained in the navigation data. As detailed in Annex A [1], for E1 and E5b, the SHS flag is included in the Type 5 words of the I/NAV navigation data stream while for E5a, the SHS flag is included in the Type 1 words of the F/NAV navigation

data stream. These are the flags that should normally be used for determining the SIS Status.

Additionally, these flags are also included in the corresponding almanac messages for indicative purposes. This allows focusing the search of satellites during initial acquisition on satellites with a healthy signal. In cases of conflict, the value in the Type 5 words of the I/Nav and the Type 1 words of the F/Nav message streams must be used, in line with section 2.3.1.3.

## 2.4.3 EXCLUDED ERRORS

The Minimum Performance Levels reported in section 3 of this OS SDD do not take into account any error source that is not under direct control of the Galileo system. Specifically excluded errors comprise those due to the effects of:

- Signal distortion caused by ionospheric and/or tropospheric propagation effects.
- Residual receiver ionospheric delay compensation errors.
- Residual receiver tropospheric delay compensation errors.
- Receiver noise (including received signal power and interference power) and resolution.
- Receiver hardware/software faults.
- Multipath and receiver multipath mitigation.
- User antenna effects.
- Receiver operator error.

<sup>8</sup>.....As an example, DF users do not need to retrieve ionospheric parameters.

## 2.5 OPERATIONAL CAPABILITY EVOLUTION

The entry into the service provision phase of the Galileo OS took place before the Galileo core infrastructure is fully deployed. As a consequence, an evolution of the performance is expected as the system, including both space segment and ground segment, reaches its full operational capability (FOC).

The minimum performance levels included in the current version of the document have been derived taking into account the current Galileo system deployment status. Future updates of the minimum performance levels are foreseen, as the Galileo system reaches its final maturity.

Information about the current Galileo system status is available to users through the European GNSS Service Centre (GSC) webpage (see section 1.6.4).

Superseded

A photograph of a person standing on the deck of a blue and orange boat, looking out at a lighthouse on a distant pier. The water is blue and the sky is clear. A large red 'Superseded' watermark is diagonally across the image.

# SECTION 3: GALILEO OS MINIMUM PERFORMANCE LEVELS

## 3.1 OVERVIEW

This section specifies the Galileo OS performance in terms of Minimum Performance Levels (MPLs) defined for the set of performance parameters described in section 2. In addition, it provides further specifications about the constellation applicable at the time of the publication of the document and the service coverage, and lists the potential conditions and constraints that are applicable for service provision.

For all MPLs, all Ages of Data (within the maximum nominal broadcast period of a healthy navigation message dataset) observed during the measurement time interval are considered.

The navigation solution is expected to meet the OS MPLs only if the usage assumptions for OS as provided in section 2.4 and specifically those related to the OS user receiver in section 2.4.1 are fulfilled.

The Galileo OS MPLs do not include any contribution that is not under the control of the Galileo system. In particular, tropospheric, ionospheric, and receiver noise contributions or interference are not included in the specifications (see also section 2.4.3).

## 3.2 GALILEO OS CONSTELLATION DEFINITION

The Galileo constellation considered as reference in the preparation of this OS SDD is reported in Table 8, and comprises 22 operational satellites.

The MPLs presented in this document are based on a constellation of at least 18 operational satellites.

The baseline Galileo constellation configuration is described in section 1.6.1 and in Annex C.

The Galileo constellation is currently under deployment. The up-to-date status of the Galileo constellation is available through the European GNSS Service Centre (GSC) webpage<sup>9</sup>. All events related to the Galileo Space Segment are communicated to users through the Notice Advisories to Galileo Users (NAGUs) provided by the GSC (see Section 1.6.4.1.1).

POSITION		SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	RAAN	ARG. PERIGEE	MEAN ANOMALY
Plane	Slot	km		deg	deg	deg	deg
A	1	29599.801	0	56.0	317.632	0	180.153
A	2	29599.801	0	56.0	317.632	0	225.153
A	3	29599.801	0	56.0	317.632	0	270.153
A	4	29599.801	0	56.0	317.632	0	315.153
A	5	29599.801	0	56.0	317.632	0	0.153
A	6	29599.801	0	56.0	317.632	0	45.153
A	7	29599.801	0	56.0	317.632	0	90.153
A	8	29599.801	0	56.0	317.632	0	135.153
B	1	29599.801	0	56.0	77.632	0	195.153
B	2	29599.801	0	56.0	77.632	0	240.153
B	4	29599.801	0	56.0	77.632	0	330.153
B	5	29599.801	0	56.0	77.632	0	15.153
B	6	29599.801	0	56.0	77.632	0	60.153
B	7	29599.801	0	56.0	77.632	0	150.153
B	8	29599.801	0	56.0	77.632	0	150.153
C	1	29599.801	0	56.0	197.632	0	210.153
C	2	29599.801	0	56.0	197.632	0	255.153
C	3	29599.801	0	56.0	197.632	0	300.153
C	4	29599.801	0	56.0	197.632	0	345.153
C	6	29599.801	0	56.0	197.632	0	75.153
C	7	29599.801	0	56.0	197.632	0	120.153
C	8	29599.801	0	56.0	197.632	0	165.153

Table 8. Galileo Constellation Parameters (Ref. Epoch: 2016/11/21 00:00:00) – Reference constellation for this OS SDD.

<sup>9</sup>..... <http://www.gsc-europa.eu/system-status/Constellation-information>

The correspondence between satellite plane and slot and Space Vehicle identifier (SVID) is also reported on the GSC webpage<sup>10</sup>.

## 3.3 GALILEO OS ACCURACY

This section provides the Minimum Performance Levels of the accuracy of the Galileo OS. The following MPLs define the OS performance in accuracy:

For ranging services:

- Galileo SIS Ranging Accuracy for any satellite;
- Galileo SIS Ranging Accuracy over all satellites.

For timing services:

- Galileo SIS UTC Time Dissemination Accuracy;
- Galileo SIS UTC Frequency Dissemination Accuracy.

The associated MPLs for the availability of services are defined in section 3.4. .

### 3.3.1 GALILEO SIS RANGING ACCURACY MPL

The Galileo OS SIS Ranging Accuracy MPL for any satellite as defined in 2.3.2.1, is specified in Table 9.

The Galileo OS SIS Ranging Accuracy MPL over all satellites as defined in 2.3.2.1, is specified in Table 10.

### 3.3.2 GALILEO SIS RANGING RATE ACCURACY MPL

The Galileo SIS Ranging Rate Accuracy MPL will be defined in a future issue of the OS SDD.

GALILEO SIS RANGING ACCURACY MPL FOR ANY SATELLITE	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>• <math>\leq 7\text{m}</math> (95%) global average, over all AODs</li> </ul>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• For any healthy OS SIS above a minimum elevation angle of 5 degrees</li> <li>• Including Broadcast Group Delay errors</li> <li>• Propagation and user contributions excluded</li> <li>• Neglecting single frequency ionospheric delay model errors<sup>11</sup></li> </ul>
For each DF combination: <ul style="list-style-type: none"> <li>• <math>\leq 7\text{m}</math> (95%) global average, over all AODs</li> </ul>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• For any healthy OS SIS above a minimum elevation angle of 5 degrees</li> <li>• Propagation and user contributions excluded</li> </ul>

Table 9. Galileo SIS Ranging Accuracy MPL for any satellite.

GALILEO SIS RANGING ACCURACY MPL OVER ALL SATELLITES	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>• <math>\leq 2\text{m}</math> (95%) over all AODs</li> </ul>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• 95<sup>th</sup> percentile of the time series of constellation average Galileo SIS Ranging Accuracy (computed as the rms of the instantaneous global average SISE)</li> </ul>
For each DF combination: <ul style="list-style-type: none"> <li>• <math>\leq 2\text{m}</math> (95%) over all AODs</li> </ul>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• 95<sup>th</sup> percentile of the time series of constellation average Galileo SIS Ranging Accuracy (computed as the rms of the instantaneous global average SISE)</li> </ul>

Table 10. Galileo SIS Ranging Accuracy MPL over all satellites.

11.... Note that although parameters for the correction of the ionospheric effect for SF users are broadcast by the Galileo OS SIS, the single-frequency ionospheric delay model errors are not accounted for in the MPL, just like any contribution to the MPL due to propagation that is not under control of the Galileo operator. This is valid throughout the document.

10....<http://www.gsc-europa.eu/system-status/orbital-and-technical-parameters>

### 3.3.3 GALILEO SIS UTC TIME DISSEMINATION ACCURACY MPL

The Galileo OS SIS UTC Time Dissemination Accuracy MPL is specified in Table 11

GALILEO SIS UTC TIME DISSEMINATION ACCURACY MPL	CONDITIONS AND CONSTRAINTS
<p>For each SF and DF combination:</p> <ul style="list-style-type: none"> <li>&lt; 30ns (95%) over all AODs</li> </ul>	<ul style="list-style-type: none"> <li>For any healthy OS SIS</li> <li>At any user location</li> <li>Normalised annually</li> <li>Propagation and user contributions excluded</li> </ul>

Table 11. Galileo SIS UTC Time Dissemination Accuracy MPL.

### 3.3.4 GALILEO SIS UTC FREQUENCY DISSEMINATION ACCURACY MPL

The OS Galileo SIS UTC Frequency Dissemination Accuracy MPL is specified in Table 12.

GALILEO SIS UTC FREQUENCY DISSEMINATION ACCURACY MPL	CONDITIONS AND CONSTRAINTS
<p>For each SF and DF combination:</p> <ul style="list-style-type: none"> <li>&lt; 3E-13( 95%) over all AODs</li> </ul>	<ul style="list-style-type: none"> <li>For any healthy OS SIS</li> <li>At any user location</li> <li>Normalised annually</li> <li>Propagation and user contributions excluded</li> </ul>

Table 12. Galileo SIS UTC Frequency Dissemination Accuracy MPL.

The following availability MPLs currently define OS availability performance:

- Per-Slot Availability.
- Availability of the Galileo OS UTC Time Dissemination Service.
- Availability of the Galileo OS position dilution of precision (PDOP).
- Availability of the Galileo OS Positioning Service.
- Availability of the Galileo OS UTC Time Determination Service.

### 3.4.1 GALILEO PER-SLOT AVAILABILITY

The OS MPL for the Per-Slot Availability is specified in in Table 13.

MPL OF THE PER-SLOT AVAILABILITY	CONDITIONS AND CONSTRAINTS
<p>For each SF:</p> <ul style="list-style-type: none"> <li>≥ 87% probability that an orbital slot in the Galileo constellation<sup>13</sup> is occupied by a Galileo satellite transmitting the healthy SF SIS</li> </ul>	<ul style="list-style-type: none"> <li>Calculated as an average of the availability of the SF SIS over all orbital slots in the Galileo satellite constellation<sup>12</sup>, normalised annually</li> <li>Including planned and unplanned outages</li> </ul>
<p>For each DF combination:</p> <ul style="list-style-type: none"> <li>≥ 87% probability that an orbital slot in the Galileo constellation<sup>13</sup> is occupied by a Galileo satellite transmitting the healthy DF SIS combination</li> </ul>	<ul style="list-style-type: none"> <li>Calculated as an average of the availability of the DF SIS combination over all orbital slots in the Galileo satellite constellation<sup>12</sup>, normalised annually</li> <li>Including planned and unplanned outages</li> </ul>

Table 13. MPL of the Per-Slot Availability.

## 3.4 GALILEO OS AVAILABILITY

This section provides the MPLs associated with the OS availability. The availability MPLs provided in this section correspond to the current Galileo deployment configuration status.

12.... The Galileo Space Segment is currently under deployment. At any time, the Galileo constellation to be taken as reference is the one published by the GSC (<http://www.gsc-europa.eu/system-status/Constellation-Information>). Since the deployment of the Galileo constellation has not been completed at the time of publication of this document, constellation maintenance and replenishment during this phase will be covered by continuation of the satellite deployment plan.

### 3.4.2 AVAILABILITY OF THE GALILEO UTC TIME DISSEMINATION SERVICE

The OS MPL for the Availability of the Galileo UTC Time Dissemination Service is specified in Table 14.

MPL OF THE AVAILABILITY OF THE GALILEO OS UTC TIME DISSEMINATION SERVICE	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>≥ 87% of time a user is provided at least one healthy SF SIS</li> </ul>	<ul style="list-style-type: none"> <li>Calculated over a period of 30 days</li> <li>Above a minimum elevation angle of 5 degrees</li> <li>From any point in the service coverage</li> <li>Including planned and unplanned outages</li> </ul>
For each DF combination: <ul style="list-style-type: none"> <li>≥ 87% of time a user is provided at least one healthy DF SIS combination</li> </ul>	<ul style="list-style-type: none"> <li>Calculated over a period of 30 days</li> <li>Above a minimum elevation angle of 5 degrees</li> <li>From any point in the service coverage</li> <li>Including planned and unplanned outages</li> </ul>

Table 14. MPL of the Availability of the Galileo OS UTC Time Dissemination Service..

### 3.4.3 AVAILABILITY OF THE GALILEO POSITION DILUTION OF PRECISION

The OS MPL for the Availability of the Galileo Position Dilution of Precision is specified in Table 15.

MPL OF THE AVAILABILITY OF THE POSITION DILUTION OF PRECISION	CONDITIONS AND CONSTRAINTS
For each SF and DF combination: <ul style="list-style-type: none"> <li>≥ 77% at average location</li> </ul>	<ul style="list-style-type: none"> <li>With a Position Dilution of Precision less than or equal to 6</li> <li>At least 4 satellites in view above a minimum elevation angle of 5 degrees</li> <li>Calculated over a period of 30 days</li> <li>Including planned and unplanned outages</li> </ul>

Table 15. MPL of the Availability of the Galileo Position Dilution Of Precision.

### 3.4.4 AVAILABILITY OF THE GALILEO POSITIONING SERVICE

The performance of the OS SIS Ranging Accuracy over all satellites (section 3.3.1) and of the Availability of the OS PDOP (section 3.4.3) support the MPL for the Availability of the Galileo Positioning Accuracy for OS. This MPL is specified in Table 16, at average user location, and in Table 17, at worst user location.

MPL OF THE AVAILABILITY OF THE POSITIONING SERVICE	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>≥ 77% at average user location</li> </ul>	<ul style="list-style-type: none"> <li>With a horizontal positioning accuracy better than 7.5 m (95%)</li> <li>With a vertical positioning accuracy better than 15 m (95%)</li> <li>At least 4 satellites in view above a minimum elevation of 5 degrees</li> <li>Calculated over a period of 30 days</li> <li>Including planned and unplanned outages</li> <li>Including Broadcast Group Delay errors</li> <li>Propagation and user contributions excluded</li> <li>Neglecting single frequency ionospheric delay model errors<sup>13</sup></li> </ul>
For each DF: <ul style="list-style-type: none"> <li>≥ 77% at average user location</li> </ul>	<ul style="list-style-type: none"> <li>With a horizontal positioning accuracy better than 7.5 m (95%)</li> <li>With a vertical positioning accuracy better than 15 m (95%)</li> <li>At least 4 satellites in view above a minimum elevation of 5 degrees</li> <li>Calculated over a period of 30 days</li> <li>Including planned and unplanned outages</li> <li>Propagation and user contributions excluded</li> </ul>

Table 16. MPL of the Availability of the Galileo Positioning service, at average user location.

<sup>13</sup>...Note that although parameters for the correction of the ionospheric effect for SF users are broadcast by the Galileo OS SIS, the single frequency ionospheric delay model errors are not accounted for.

MPL OF THE AVAILABILITY OF THE POSITIONING SERVICE	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>• <math>\geq 70\%</math> at worst user location</li> </ul>	<ul style="list-style-type: none"> <li>• With a horizontal positioning accuracy better than 7.5 m (95%)</li> <li>• With a vertical positioning accuracy better than 15 m (95%)</li> <li>• At least 4 satellites in view above a minimum elevation of 5 degrees</li> <li>• Calculated over a period of 30 days</li> <li>• Including planned and unplanned outages</li> <li>• Including Broadcast Group Delay errors</li> <li>• Propagation and user contributions excluded</li> <li>• Neglecting single frequency ionospheric delay model errors<sup>14</sup></li> </ul>
For each DF: <ul style="list-style-type: none"> <li>• <math>\geq 70\%</math> at worst user location</li> </ul>	<ul style="list-style-type: none"> <li>• With a horizontal positioning accuracy better than 7.5 m (95%)</li> <li>• With a vertical positioning accuracy better than 15 m (95%)</li> <li>• At least 4 satellites in view above a minimum elevation of 5 degrees</li> <li>• Calculated over a period of 30 days</li> <li>• Including planned and unplanned outages</li> <li>• Propagation and user contributions excluded</li> </ul>

Table 17. MPL of the Availability of the Galileo Positioning service, at worst user location.

### 3.4.5 AVAILABILITY OF THE GALILEO UTC TIME DETERMINATION SERVICE

The OS MPL for the Availability of the Galileo UTC Time Determination service derives from the MPL defined for the OS SIS Ranging Accuracy over all satellites (3.3.1), from the MPL defined for the Galileo SIS UTC Time Dissemination Accuracy (3.3.3), and from the MPL for the Availability of the Galileo UTC Time Dissemination Service (3.4.2). These three MPLs result in an MPL for the Availability of the Galileo UTC Time Determination service as specified in Table 18, for any point in the service coverage area. Comparing with Table 11, the UTC Time Determination Accuracy is only marginally greater than the UTC Time Dissemination Accuracy, which does not take into account the contribution of the Galileo System Time estimation (see Figure 5).

MPL OF THE AVAILABILITY OF THE UTC TIME DETERMINATION SERVICE	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>• <math>\geq 87\%</math></li> </ul>	<ul style="list-style-type: none"> <li>• With UTC Time Determination accuracy better than 31 ns (95%)</li> <li>• At least 1 satellite in view above a minimum elevation of 5 degrees</li> <li>• For users at a known location</li> <li>• From any point in the service coverage</li> <li>• Calculated over a period of 30 days</li> <li>• Including planned and unplanned outages</li> <li>• Including Broadcast Group Delay errors</li> <li>• Propagation and user contributions excluded</li> <li>• Neglecting single frequency ionospheric delay model errors<sup>14</sup></li> </ul>
For each DF: <ul style="list-style-type: none"> <li>• <math>\geq 87\%</math></li> </ul>	<ul style="list-style-type: none"> <li>• With UTC Time Determination accuracy better than 31 ns (95%)</li> <li>• At least 1 satellite in view above a minimum elevation of 5 degrees</li> <li>• For users at a known location</li> <li>• From any point in the service coverage</li> <li>• Calculated over a period of 30 days</li> <li>• Including planned and unplanned outages</li> <li>• Propagation and user contributions excluded</li> </ul>

Table 18. MPL of the Availability of the Galileo UTC Time Determination service, for any point in the service coverage.

<sup>14</sup>.... Note that although parameters for the correction of the ionospheric effect for SF users are broadcast by the Galileo OS SIS, the single frequency ionospheric delay model errors are not accounted for.

## 3.5 ADDITIONAL FUNCTIONALITY

### 3.5.1 GALILEO OS COMPATIBILITY AND INTEROPERABILITY WITH OTHER GNSS

The Galileo OS is compatible, i.e. operates on no harmful interference basis, with the other GNSS services, such as GPS, GLONASS and Beidou services. One of the main drivers of the Galileo system design has been its interoperability with other GNSS. In the GNSS context, interoperability should be understood as the capability for user equipment to exploit available navigation signals of different GNSS and to produce a combined solution that generally exhibits performance benefits (e.g. better accuracy, higher availability) with respect to the standalone system solution.

The design of the Galileo system has addressed interoperability from different perspectives:

- The Galileo frequency bands have been allocated in the Radio Navigation Satellite Services (RNSS) part of the spectrum. The OS carrier frequencies (in particular E1, and E5a) and their modulation characteristics simplify the combined use of Galileo with other constellations (GPS, GLONASS, and Beidou).
- The Galileo terrestrial and time reference systems have been defined and are continuously aligned to the corresponding international terrestrial and time reference systems, ITRF and UTC, respectively (see sections 1.6.5.1 and 1.6.5.2).

Furthermore, Galileo implements additional features in order to support an enhanced level of interoperability with GPS, as explained in the next section.

#### 3.5.1.1 GALILEO SYSTEM TIME TO GPS TIME OFFSET

Galileo System Time (GST) (see section 1.6.5.2) and GPS time are two independent continuous timescales steered respectively to UTC(k) and UTC(USNO). Although the coherence of all UTC realisations inherently provides a high degree of interoperability between Galileo and GPS, the actual physical realisations are independent, hence Galileo and GPS system times are different and this difference is variable with time.

This inconsistency between Galileo and GPS time references can be solved either by autonomous calculation in the user equipment or by provision of system time offsets by any of the participating GNSS.

For autonomous calculation in the user equipment, an additional unknown parameter is introduced into the positioning system of equations for the a priori unknown time difference between the systems. In solving the set of equations, the time difference is also inherently resolved. The disadvantage of this approach is that at least one additional line-of-sight measurement is required for solving the set of equations. Effectively, at least one available satellite of the combined visible constellation is dedicated to solving for the time difference.

The Galileo system provides the “Galileo to GPS Time Offset” (GGTO) as part of its navigation message. The MPLs for the GGTO parameter are presented in section 3.5.1.2.

#### 3.5.1.2 GALILEO OS GST TO GPS TIME OFFSET DETERMINATION PERFORMANCE

The accuracy in determination of the GST-GPS time offset is defined as the 95<sup>th</sup> percentile of the difference between the GST versus GPS time as computed using the Galileo navigation message and the true GGTO, averaged over one day. True GGTO is the GST-GPS Time offset as observed through the SIS of the two systems.

The availability of determination of the GST-GPS time offset is defined as the global average percentage of time that the GGTO is broadcast on one or more healthy SIS receivable above a minimum elevation angle of 5 degrees from any point in the service coverage (including both planned and unplanned outages).

The GGTO determination accuracy for the OS is specified in Table 19. The respective GGTO determination availability is specified in Table 20.

MPL OF GALILEO GST-GPS TIME OFFSET DETERMINATION ACCURACY	CONDITIONS AND CONSTRAINTS
Any OS SIS: <ul style="list-style-type: none"> <li>&lt; 20ns (95%) difference between the broadcast GGTO and the true GGTO, averaged daily</li> </ul>	<ul style="list-style-type: none"> <li>For any healthy OS SIS</li> <li>Normalised annually</li> <li>Propagation and user contributions excluded</li> </ul>

Table 19. MPL of Galileo GST-GPS Time Offset Determination Accuracy.

MPL OF GALILEO GST-GPS TIME OFFSET DETERMINATION AVAILABILITY	CONDITIONS AND CONSTRAINTS
Any SIS OS: <ul style="list-style-type: none"> <li>≥ 80% of time that GGTO is broadcast on at least one healthy SIS</li> </ul>	<ul style="list-style-type: none"> <li>Above a minimum elevation angle of 5 degrees</li> <li>From any point in the service coverage area</li> <li>Normalised annually</li> <li>Including planned and unplanned outages</li> </ul>

Table 20. MPL of Galileo GST-GPS Time Offset Determination Availability.

### 3.6.1 TIMELY PUBLICATION OF NAGUS

The Timely publication of NAGUs refers to the time intervals within which Galileo NAGUs are published, before any planned event or after any unplanned event.

The MPL for the Timely publication of NAGUs for the OS is specified in Table 21.

MPL OF THE TIMELY PUBLICATION OF NAGUS	CONDITIONS AND CONSTRAINTS
For scheduled events affecting the service <ul style="list-style-type: none"> <li>≥ 24 hours before the service is affected</li> </ul>	<ul style="list-style-type: none"> <li>Including both Planned and General NAGUs</li> </ul>
For unscheduled outages or events affecting the service <ul style="list-style-type: none"> <li>≤ 72 hours after the event affecting the service is detected</li> </ul>	<ul style="list-style-type: none"> <li>Only for Unplanned NAGUs</li> </ul>

Table 21. MPL of the Timely publication of NAGUs.

## 3.6 PERFORMANCE LEVEL FOR THE GNSS SERVICE CENTRE

As described in section 1.6.4, the GSC acts as the single interface for help and support between the Galileo OS user community and the Galileo system infrastructure and operator. It is responsible, among other tasks, for reporting on the status of the service through the dissemination of NAGUs and for providing helpdesk service to the users.

These two services by the GSC are part of the overall service provided by Galileo to its users and are subject to MPLs.

The GSC performance is characterised by the Timely publication of NAGUs.

# 1.1.1.1. Modulation Scheme

$$am3_{j,k} = fm3_{1,j,k} \left(1 - \frac{Az_R}{100}\right) + fm3_{2,j,k} \frac{Az_R}{100}$$

The diagram in Figure 3 provides a generic view of the E5 signal AltBOC modulation generation.

The E5 signal components are generated according to the following:

- $e_{E5a-I}$  from the F/NAV navigation data stream  $D_{E5a-I}$  modulated with the unencrypted ranging code  $C_{E5a-I}$  (pilot component)
- $e_{E5a-Q}$  from the unencrypted ranging code  $C_{E5}$
- $e_{E5b-I}$  from the I/NAV navigation data stream  $D_{E5b-I}$  modulated with the unencrypted ranging code  $C_{E5b-I}$  (pilot component)
- $e_{E5b-Q}$  from the unencrypted ranging code  $C_{E5b-Q}$

The ionosphere is a region of weakly ionised gas in the Earth's atmosphere lying between about 50 kilometers up to several thousand kilometers from Earth's surface. Solar radiation is responsible for this ionisation producing free electrons and ions. The ionospheric refractive index (the ratio between the speed of propagation in the media and the speed of propagation in vacuum) is related to the number of free electrons through the propagation path. For this purpose, the Total Electron Content (TEC) is defined as the electron density integrated along a path (vertical) path between two points (e.g. a satellite and a receiver);  $E_{5a-I}$  is expressed in TEC units (TECU) where 1 TECU equals 1016 electrons/m<sup>2</sup>. The ionosphere affects radio wave propagation in various ways such as refraction, absorption, Faraday rotation, group delay, time dispersion or scintillations, being most of them related to TEC in the propagation path. These effects are dispersive, as they depend on the signal frequency.

## ANNEX A: REFERENCE DOCUMENTS

AltBOC MUX

The secondary codes are fixed sequences as defined in hexadecimal notation in Table 19 and Table 20, following again the convention used in paragraph 3.4.1.1. For secondary codes whose length is not divisible by four (case of CS251 only), the last (most right-hand) hexadecimal symbol is obtained by filling up the last group of code chips with zeros at the end in time (to the right), to reach a final length of 4 binary symbols. Those two tables provide as well the code identifiers together with the code lengths, the number of hexadecimal symbols and the number of filled zeros

The ionosphere is classically sub-divided in layers characterized by different properties: D, E, F1 and F2, the latter being largely responsible for the ionospheric effects which typically affect GNSS applications.

$$e_{E5a-I}(t) = \sum_{i=-\infty}^{+\infty} [C_{E5a-I}, i]_{L_{E5a-I}} d_{E5a-I}, [i]_{DC_{E5a-I}} \text{rect}_{T_{C,E5a-I}}(t - iT_{C,E5a-I})]$$

$$e_{E5a-Q}(t) = \sum_{i=-\infty}^{+\infty} [C_{E5a-Q}, i]_{L_{E5a-Q}} \text{rect}_{T_{C,E5a-Q}}(t - iT_{C,E5a-Q})]$$

$$e_{E5b-I}(t) = \sum_{i=-\infty}^{+\infty} [C_{E5b-I}, i]_{L_{E5b-I}} d_{E5b-I}, [i]_{DC_{E5b-I}} \text{rect}_{T_{C,E5b-I}}(t - iT_{C,E5b-I})]$$

$$e_{E5b-Q}(t) = \sum_{i=-\infty}^{+\infty} [C_{E5b-Q}, i]_{L_{E5b-Q}} \text{rect}_{T_{C,E5b-Q}}(t - iT_{C,E5b-Q})]$$

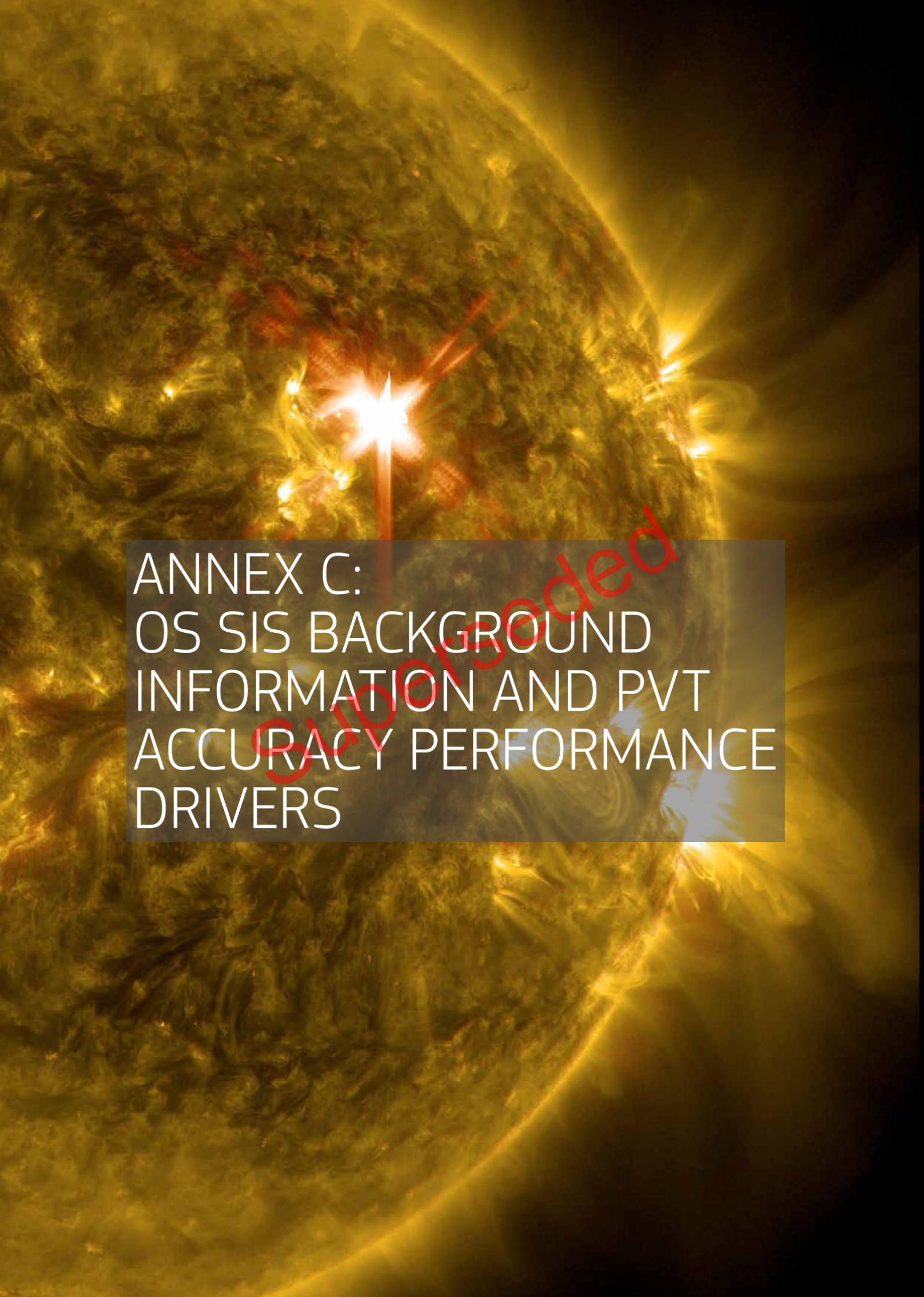
This section identifies the documents explicitly referenced in this Open Service – Service Definition Document.

REFERENCE	TITLE	ISSUE
[1]	European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (OS SIS ICD).	The most up-to-date issue. (Available on the web page of the <a href="#">Galileo Service Centre</a> )
[2]	Ionospheric Correction Algorithm for Galileo Single Frequency Users.	Issue 1.2, European Union, September 2016. (Available on the web page of the <a href="#">Galileo Service Centre</a> )



# ANNEX B: ABBREVIATIONS AND ACRONYMS

<b>AltBOC</b>	Alternative BOC modulation	<b>IOD</b>	Issue of Data
<b>AOD</b>	Age of Data	<b>ITRF</b>	International Terrestrial Reference Frame
<b>ARAIM</b>	Advanced Receiver Autonomous Integrity Monitoring	<b>MPL</b>	Minimum Performance Level
<b>AUL</b>	Average User Location	<b>NAGU</b>	Notice Advisory to Galileo Users
<b>BGD</b>	Broadcast Group Delay	<b>NAPA</b>	No Accuracy Prediction Available
<b>BIPM</b>	International Bureau of Weights and Measures	<b>NDV</b>	Navigation Data Valid
<b>BOC</b>	Binary Offset Carrier modulation	<b>OS</b>	Open Service
<b>CBOC</b>	Composite BOC modulation	<b>PDOP</b>	Position Dilution of Precision
<b>CIRS</b>	Celestial Intermediate Reference System	<b>PRS</b>	Public Regulated Service
<b>CRC</b>	Cyclic Redundancy Check	<b>PVT</b>	Position, Time, and Velocity
<b>DF</b>	Dual-Frequency	<b>RAAN</b>	Right Ascension of the Ascending Node
<b>DOP</b>	Dilution Of Precision	<b>RAIM</b>	Receiver Autonomous Integrity Monitoring
<b>DVS</b>	Data Validity Status	<b>RF</b>	Radio Frequency
<b>EGNSS</b>	European GNSS	<b>RNSS</b>	Radio Navigation Satellite Services
<b>EU</b>	European Union	<b>SAR</b>	Search And Rescue
<b>F/NAV</b>	Navigation Message broadcast on Galileo E5a signal	<b>SBAS</b>	Satellite-Based Augmentation System
<b>FEC</b>	Forward Error Correction	<b>SDD</b>	Service Definition Document
<b>FOC</b>	Full Operational Capability	<b>SF</b>	Single-Frequency
<b>GBAS</b>	Ground-Based Augmentation System	<b>SHS</b>	Signal Health Status
<b>GCC</b>	Galileo Control Centre	<b>SIS</b>	Signal In Space
<b>GCS</b>	Ground Control Segment	<b>SISA</b>	SIS Accuracy
<b>GDOP</b>	Geometric Dilution Of Precision	<b>SISE</b>	SIS Ranging Error
<b>GGTO</b>	Galileo-GPS Time Offset	<b>SV</b>	Space Vehicle
<b>GLONASS</b>	Globalnaya Navigatsionnaya Sputnikovaya Sistema	<b>SVID</b>	Space Vehicle Identifier
<b>GMS</b>	Ground Mission Segment	<b>TAI</b>	International Atomic Time
<b>GNSS</b>	Global Navigation Satellite System	<b>TDOP</b>	Time Dilution Of Precision
<b>GPS</b>	Global Positioning System	<b>TTDOP</b>	Time Transfer Dilution Of Precision
<b>GRC</b>	Galileo Reference Centre	<b>TOE</b>	Time of Ephemeris
<b>GRSP</b>	Geodetic Reference Service Provider	<b>TE</b>	Time Error
<b>GSA</b>	European GNSS Agency	<b>TSP</b>	Time Service Provider
<b>GSC</b>	European GNSS Service Centre	<b>TTC</b>	Telemetry, Tracking, and Commanding
<b>GSMC</b>	Galileo Security Monitoring Centre	<b>UEE</b>	User Equipment Error
<b>GSS</b>	Galileo Sensor Station	<b>UERE</b>	User Equivalent Range Error
<b>GST</b>	Galileo System Time	<b>ULS</b>	Galileo Uplink Station
<b>GTRF</b>	Galileo Terrestrial Reference Frame	<b>USNO</b>	United States Naval Observatory
<b>HDOP</b>	Horizontal Dilution Of Precision	<b>UTC</b>	Coordinated Universal Time
<b>I/NAV</b>	Navigation message broadcast on Galileo E5b and E1 signals	<b>VDOP</b>	Vertical Dilution Of Precision
<b>ICD</b>	Interface Control Document	<b>WUL</b>	Worst User Location
<b>IERS</b>	International Earth Rotation and Reference Systems Service	<b>WWG</b>	Working Without Guarantee



ANNEX C:  
OS SIS BACKGROUND  
INFORMATION AND PVT  
ACCURACY PERFORMANCE  
DRIVERS

# C.1. INTRODUCTION

## C.1.1 SCOPE

This Annex comprises additional background information and details regarding the Galileo OS SIS performance parameters.

## C.1.2 LIMITATIONS

The information in this Annex is provided exclusively for reference and does not in any way affect the MPLs presented in section 3 of this OS SDD.

will be decided at the time of deployment of the spare capability.

The reference constellation geometry of the 24-slot Galileo constellation is defined in Table 1. The Keplerian parameters are given in the Celestial Intermediate Reference System (CIRS) frame<sup>15</sup>.

Table 23 shows a snapshot of the reference orbit at the reference epoch 2016/11/21 00:00:00 UTC. The reference RAAN, argument of perigee and Mean Anomaly are dynamic parameters, while the others are static. To calculate values for other epochs, users are advised to use a linear extrapolation for the RAAN, argument of perigee and the Mean Anomaly with the temporal rates shown in Table 22.

# C.2. CONSTELLATION

## C.2.1 RELATIONSHIP WITH SECTION 3.2

Section 3.2 of this document provides the Galileo constellation operational configuration at the time of the publication of this document. In the next section, information is provided on the Galileo constellation expected at FOC.

REFERENCE PARAMETER RATES	SLOTS
$d(\text{RAAN})/dt$	-0.02764398 deg/day
$d(\text{Arg. peri})/dt$	0.00000000 deg/day
$d(\text{Mean Anomaly})/dt$	613.72253566 deg/day

Table 22. Galileo Constellation Reference Technical Parameters.

## C.2.2 BASELINE 24-SLOT CONSTELLATION CONFIGURATION

The baseline Galileo constellation configuration is defined as a 24/3/1 Walker constellation: 24 nominal Medium Earth Orbit satellites are arranged in 3 orbital planes, with their ascending nodes uniformly distributed at intervals of 120 degrees, inclined at 56 degrees with respect to the Equator.

Each orbital plane includes 8 satellites uniformly distributed within the plane, at intervals of 45 degrees of argument of latitude. The angular shift between satellites in two adjacent planes is 15 degrees. The constellation is complemented by spare satellites that can be repositioned to any given slot depending on maintenance or service evolution needs. The location of the spare satellites in each plane is not yet frozen and

15... The CIRS is a geocentric coordinate system based on the current position of the Celestial Intermediate Pole. In this system, the right ascension is calculated along the Celestial Intermediate Equator from the Celestial Intermediate Origin, a point close to the vernal equinox. The exact definition can be found in the Nomenclature for Fundamental Astronomy Glossary edited by the International Astronomical Union.

POSITION		SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	RAAN	ARG. PERIGEE	MEAN ANOMALY
Plane	Slot	Km		deg	deg	deg	deg
A	1	29599.801	0	56	317.632	0	180.153
A	2	29599.801	0	56	317.632	0	225.153
A	3	29599.801	0	56	317.632	0	270.153
A	4	29599.801	0	56	317.632	0	315.153
A	5	29599.801	0	56	317.632	0	0.153
A	6	29599.801	0	56	317.632	0	45.153
A	7	29599.801	0	56	317.632	0	90.153
A	8	29599.801	0	56	317.632	0	135.153
B	1	29599.801	0	56	77.632	0	195.153
B	2	29599.801	0	56	77.632	0	240.153
B	3	29599.801	0	56	77.632	0	285.153
B	4	29599.801	0	56	77.632	0	330.153
B	5	29599.801	0	56	77.632	0	15.153
B	6	29599.801	0	56	77.632	0	60.153
B	7	29599.801	0	56	77.632	0	105.153
B	8	29599.801	0	56	77.632	0	150.153
C	1	29599.801	0	56	197.632	0	210.153
C	2	29599.801	0	56	197.632	0	255.153
C	3	29599.801	0	56	197.632	0	300.153
C	4	29599.801	0	56	197.632	0	345.153
C	5	29599.801	0	56	197.632	0	30.153
C	6	29599.801	0	56	197.632	0	75.153
C	7	29599.801	0	56	197.632	0	120.153
C	8	29599.801	0	56	197.632	0	165.153

Table 23. Galileo Constellation at FOC. Reference Geometry at 2016/11/21 00:00:00 UTC.

## C.3. SERVICE COVERAGE

### C.3.1 RELATIONSHIP WITH SECTION 3.2

This section of the Annex provides further information regarding the service coverage, particularly with respect to the coverage from each Galileo satellite.

### C.3.2 PER-SATELLITE COVERAGE

#### C.3.2.1. MASKING ANGLES

The Galileo OS SIS ICD (Annex A [1]) defines the minimum power levels of Galileo signals above a 5 degree elevation angle. However, this definition does not recommend or impose any specific minimum user masking angle.

The Galileo user masking angle is a function of various factors: the SIS ICD defined minimum user-received power levels, the specific signals tracked, the Galileo user receiver antenna gain patterns for each frequency, the receiver front-end sensitivity at each frequency, and the particular usage objective, as well as other signal environment and user receiver related factors.

For the scope of the assessments in this SDD a typical minimum user elevation angle of 5 degrees has been used. Other user needs might mandate different minimum elevation angles.

### C.3.2.2. SATELLITE FOOTPRINT

The footprint of a satellite is defined as the fraction of the surface of the Earth that is illuminated by signals from that particular satellite. The footprint of each satellite occupying a slot in the baseline 24-slot constellation covers under purely geometrical aspects approximately 39% of the Earth's surface at 0 degrees minimum user elevation angle. However, the footprint area is reduced by the consideration of user elevation masking angle. With a 5-degree user masking angle, the satellite's footprint is reduced to roughly one-third of the Earth's surface (35%).

### C.3.3 SERVICE VOLUME

The terrestrial service volume defines the region on and around Earth in which the Galileo services are provided. The terrestrial service volume is defined as the region extending from the surface of the Earth up to an altitude of 30.48 km above the surface of the Earth.

## C.4. ACCURACY

### C.4.1 RELATIONSHIP WITH SECTION 3.3

To complement the information provided in section 3.3 of the document, this part of Annex C provides further details about several aspects concerning the definition of the SISE accuracy and its behaviour in time. In addition, insight is provided about how to estimate the error in position and time experienced by Galileo users, through the definition of the User Equivalent Range Error and of the Position Dilution Of Precision.

### C.4.2 DEFINITION OF SIGNAL-IN-SPACE RANGING ERROR

The Signal in Space Ranging Error (SISE) is defined as the difference of the satellite position and time as broadcast by the navigation message and the true satellite position and time, projected on the user-satellite direction. The statistical characteristic of the SISE is the system contribution to the Galileo User Equivalent Range Error (UERE). The following section illustrates the SISE performance metrics used for the Galileo system performance verification.

### C.4.3 INSTANTANEOUS SISE PERFORMANCE METRICS

The instantaneous SISE is computed as the difference between the predicted satellite position and time, based on the broadcast navigation message, with a posteriori precise clock and orbit estimations.

The SISE inside the satellite footprint is typically characterised either as a Global Average or as the SISE at the Worst User Location (WUL).

The Global Average SISE can be determined in two ways, numerically on a grid or analytically.

#### C.4.3.1. NUMERICAL DERIVATION

The Global Average SISE can be evaluated by computing the instantaneous SISE at grid points evenly distributed over the satellite service area.

The global average can be computed as the RMS of the instantaneous SISE values at all grid points in the visibility footprint of the satellite at each time step.

The number of grid points in the satellite footprint is typically a few hundreds to thousand points. To compute statistics of the Global Average SISE a typical time interval between step is of the order of 5 minutes.

The maximum error, i.e. the SISE at the Worst User Location, typically occurs at the edge of the visibility cone, as shown in Figure 6.

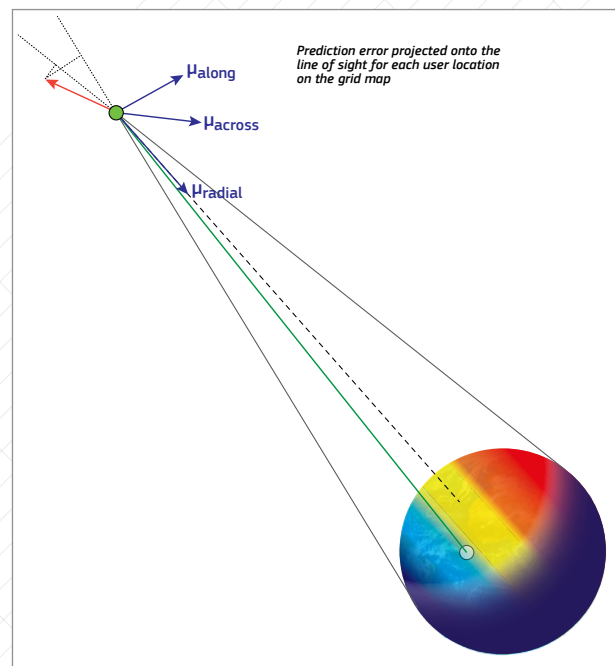


Figure 6. SISE projection onto the line of sight for each user location

### C.4.3.2. ANALYTICAL DERIVATION

The instantaneous global average SISE value can be derived analytically from the Galileo satellite's along-track (A), cross-track (C) and radial (R) orbit error components and its total SIS clock prediction error (CLK) by means of the following approximation formula<sup>16</sup>:

$$SISE_{GlobalAverage}(t) = \sqrt{0.96910 \cdot R(t)^2 + CLK(t)^2 + 0.01545 \cdot (A(t)^2 + C(t)^2) + 1.96881 \cdot CLK(t) \cdot R(t)} \quad \text{Eq. 1}$$

The following convention has been considered for clock and orbit components:

- All errors are computed as the broadcast value minus the precise reference value.
- Radial direction: from the satellite towards the Earth centre.
- Cross direction: direction perpendicular to the orbital plane aligned with the cross product of the radius and velocity.
- Along direction: perpendicular to the radius in the orbital plane, positive in the same semi-plane of the velocity.

Segment and its usage at user level. Aging of the data (characterised by AOD) impacts the accuracy of the orbit and clock models. The accuracy of their prediction inevitably degrades with higher ages.

Dissemination of the navigation message is a compromise between upload frequency and navigation data accuracy. A high upload frequency ensures a low age of data (better orbit and clock prediction accuracy) but also requires more frequent decoding of the message by users.

The age of ephemeris is the time elapsed between the reference ToE (set at the beginning of each batch) and the time of usage of the ephemeris by a receiver. The age of ephemeris can be checked by the user<sup>17</sup>. Figure 7 illustrates the SISE evolution as a function of the age of ephemeris and typical and maximum age of data service envelopes.

## C.4.4 TIME DEPENDENCY

### C.4.4.1. SISE EVOLUTION WITH UPLOADS AS A FUNCTION OF TIME

The Galileo system generates and uploads 8 batches of navigation data (see the Galileo OS SIS ICD (Annex A [1]) for more details). In nominal operations each navigation message can potentially be broadcast for up to 3 hours.

The Age of Data (AOD) is the elapsed time between the generation of a navigation message by the Ground

The nominal service envelope is given by the lower bound illustrated in Figure 7. For extended operations the message error could grow within the area defined as maximum. The system will target operations in the nominal service envelope.

The navigation dataset refresh rate is a parameter defined by the system. The typical refresh rate of the navigation data broadcast by the satellites ranges from 10 minutes to 3 hours.

16.... The coefficients provided in Eq. (1) are valid when an elevation masking angle of 5 degrees is applied by the Galileo receivers.

17.... The following procedure can be used to estimate the age of ephemeris as prediction time from the reference Time of Ephemeris ( $t - t_{oe}$ ). Applying this algorithm, users are able to compare the age of the navigation parameters they have available with the maximum nominal broadcast period of a healthy navigation message data set. The Age of Ephemeris  $t_k$  is defined as follows (see also Annex A [1]):

$$t_k = t - t_{oe}$$

where

$t$ ..... is the Time of Reception of the message in GST time [s] based on the broadcast Time Of Week (TOW), defined as the number of seconds that have occurred since the transition from the previous week,

ranging from 0 to 604799 seconds and reset to zero at the end of each week (00:00 Sunday).

$t_{oe}$ ..... is the Time of Ephemeris in GST time [s] (as for  $t$  ranging from 0 to 604799 seconds), as broadcast by the navigation message.

If a receiver wishes to check whether the age of ephemeris of a certain set of navigation data is within a certain time interval VT it will have to evaluate the following inequality:

$$0 \leq t_k \leq VT$$

Note that, as explained in Annex A [1], note to Table 58,  $t_k$  is the actual total time difference between the broadcast GST and the Time of Ephemeris accounting for the possible beginning or end of week crossover. To take this into account, if  $t_k$  is greater than 302400 second, 604800 seconds must be subtracted from  $t_k$ . If  $t_k$  is less than -302400 seconds, 604800 seconds must be added to  $t_k$ .

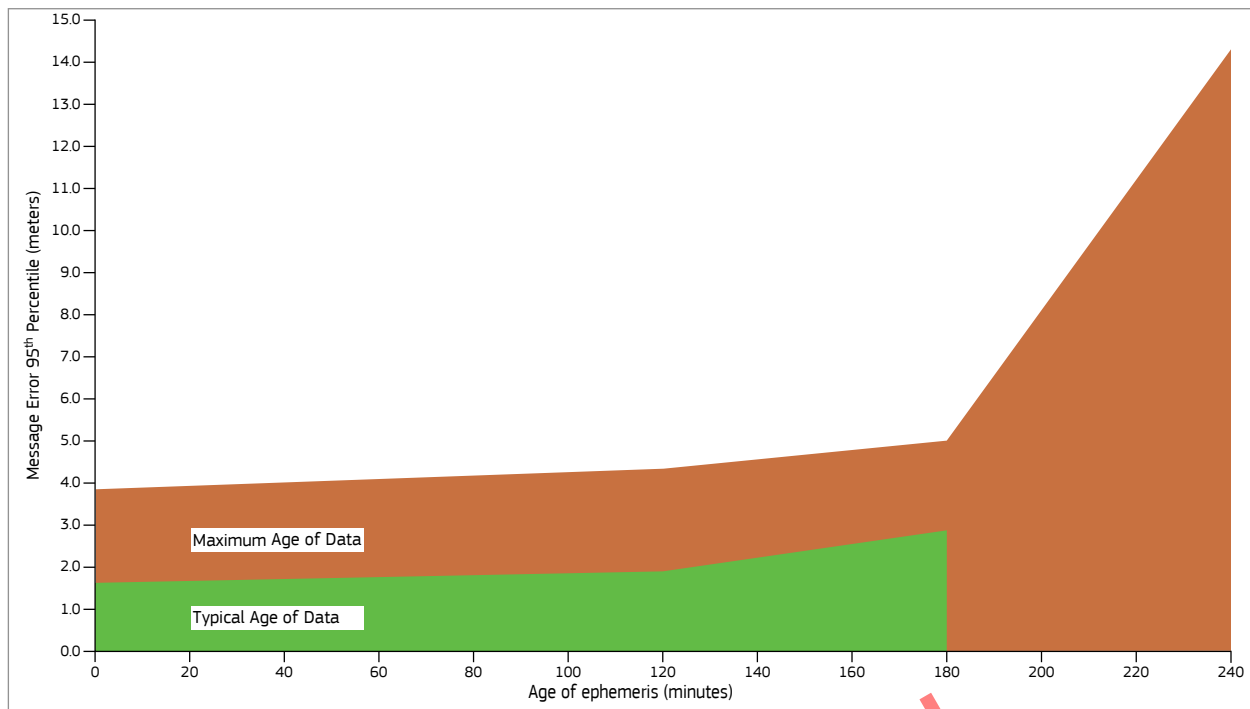


Figure 7. Typical SISE vs. Prediction Time from ToE (all batches). For illustration only - Performance will gradually improve over time toward the full system deployment.

The maximum nominal broadcast period of a healthy navigation message data set is currently 4 hours. In nominal operations, a navigation message data set is usually superseded before its expiration at 4 hours by the broadcast of a new navigation message data set.

As specified in section 2.4.1 the Galileo OS Minimum Performance Levels are expected to be met only if the navigation solution is computed by a receiver employing Healthy SIS and using the navigation parameters retrieved from the most recent navigation data set broadcast by the Galileo system after the start of the current receiver operation. The utilisation by a receiver of navigation parameters stored during previous receiver operations implies that the navigation performance that can be achieved is not expected to meet the Minimum Performance Level. Furthermore, given the way the DVS and SHS flags can be triggered, a navigation data set within the maximum nominal broadcast period of a healthy navigation message data set but not retrieved from the currently broadcast SIS might lead to the use of non-Healthy signals: the use of an old navigation data set stored in the memory of the receiver instead of the most recent data set transmitted by Galileo is at the user's own risk.

Concerning the GST-UTC conversion parameters, in the current system configuration they are updated daily (although this may change in future configurations).

With respect to the almanacs, their refresh rate is the same as for the navigation data.

#### C.4.5 UERE BUDGET

The User Equivalent Ranging Error (UERE) quantifies the distribution that describes the pseudorange errors of a specific set of user receiver measurements. The UERE includes the following contributions:

- Signal-In-Space Range Error (SISE). The Signal-In-Space Range Error is the satellite-to-user range error due to satellite signal generation and navigation message clock and ephemeris errors, which is a function of time and user location within the satellite coverage area.
- User Equipment Error (UEE). The User Equipment Error is the satellite-to-user range error due to all residual error contributions in the range domain that are not under the direct control of the GNSS system.

The UERE breakdown into SISE and UEE distributions is important in order to differentiate between the contributions under control of the system and those arising from factors not controlled by the Galileo system, and to compare their relative effect on the overall pseudorange error.

The true characteristics of SISE and UEE distributions are not necessarily Gaussian. However, both SISE and UEE can be considered sufficiently close to unbiased, uncorrelated Gaussian distributions, and hence SISE and UEE are expressed by means of their standard deviations.

Under this assumption, the resulting UERE is the standard deviation of the pseudorange error distribution:

$$UERE = \sqrt{SISE^2 + UEE^2} \quad \text{Eq. 2}$$

#### C.4.5.1. TYPICAL UERE BUDGETS

Table 24 and Table 25 show typical UERE budgets in nominal operations for single frequency rural pedestrian and dual frequency rural vehicle users, respectively. (Note that these two typical error budgets are based on different environmental assumptions and dynamics that explain the differences in the receiver dependent values).

These UERE budgets are shown for illustration purpose only, in particular for those contributions related to the receiver.

ERROR SOURCE	[METERS]
Signal in Space Ranging Error (SISE)	0.67(*)
Residual ionospheric error	6 (5°) - 3 (90°)
Residual Tropospheric error	1.35 (5°) - 0.14 (90°)
Thermal noise, Interference, Multipath	0.69 (5°) - 0.63 (90°)
Satellite BGD error	0.30
Code-Carrier ionospheric divergence error	0.30
Total (1σ error)	6.24 (5°) - 3.17 (90°)

Table 24. Typical UERE budget for Single Frequency E1 - Rural Pedestrian (RP) User Environment (\*\*).

ERROR SOURCE	[METERS]
Signal In Space Ranging Error (SISE)	0.67(*)
Residual Ionospheric error	0.08 (5°) - 0.03 (90°)
Residual Tropospheric error	1.35 (5°) - 0.14 (90°)
Thermal noise, Interference, Multipath	0.50 (5°) - 0.23 (90°)
Satellite BGD error	0.0
Code-Carrier Ionospheric divergence error	0.0
Total (1σ error)	1.59 (5°) - 0.72 (90°)

Table 25. Typical UERE budget for Dual Frequency E1/E5a - Rural Vehicle (RV) User Environment (\*\*).

#### C.4.5.2. DEFINITION OF DILUTION OF PRECISION

The relative user-tracked transmitter geometry at a given point in time defines the mapping function that relates the UERE to a PVT error distribution. The parameter that provides the relation between the error contributions in the range domain and in the position and time domains is called the "Dilution Of Precision" (DOP).

Considering the Cartesian coordinates  $x_p, y_p, z_p$  for the  $i$ -th satellite and  $x_u, y_u, z_u$  of the user receiver, and calling

$$a_{wi} = \frac{w_i - w_u}{\hat{r}}$$

the  $w$ -component of the unit vectors from the position of the receiver (to be calculated) to satellite  $i$ , it can be shown that the covariance matrix of the vector solution  $ds$  of the navigation equation, representing the error of the position vector, is given by

$$\text{cov}(ds) = (H^T H)^{-1} UERE^2 \quad \text{Eq. 3}$$

where

$$H = \begin{bmatrix} a_{x1} & a_{y1} & a_{z1} & 1 \\ a_{x2} & a_{y2} & a_{z2} & 1 \\ a_{x3} & a_{y3} & a_{z3} & 1 \\ a_{x4} & a_{y4} & a_{z4} & 1 \end{bmatrix} \quad \text{Eq. 4}$$

In other words, the components of the matrix  $(H^T H)^{-1}$  quantify how the UERE is projected onto the position and time error components. It is assumed (for simplicity) that the same UERE does apply for each pseudorange measurement.

Eq. (5) shows the case where observations are available from 4 satellites. If more than four observations are available, then corresponding rows must be added to the matrix  $H$ .

(\*) The values of the Galileo SISE, for each satellite and for the constellation are reported in the Open Service Quarterly Performance Reports, published quarterly and made available for download from the GSC website.

(\*\*) Typical range of elevation-dependent error sources are provided.

If the elements of the matrix  $(H^TH)^{-1}$  in Eq. (3) are identified as:

$$(H^TH)^{-1} = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} & \sigma_{xt} \\ \sigma_{yx} & \sigma_y^2 & \sigma_{yz} & \sigma_{yt} \\ \sigma_{zx} & \sigma_{zy} & \sigma_z^2 & \sigma_{zt} \\ \sigma_{xt} & \sigma_{yt} & \sigma_{zt} & \sigma_t^2 \end{bmatrix} \quad \text{Eq. 5}$$

the following components of DOP can be defined for a PVT solution:

- The Horizontal DOP (HDOP) is the scale factor to be applied to the UERE to obtain the corresponding position error in the local horizontal plane.

$$\text{HDOP} = \sqrt{\sigma_x^2 + \sigma_y^2} \quad \text{Eq. 6}$$

- The Vertical DOP (VDOP) is the scale factor to be applied to the UERE to obtain the corresponding position error in the local vertical plane.

$$\text{VDOP} = \sqrt{\sigma_z^2} \quad \text{Eq. 7}$$

- The Position DOP (PDOP) is the scale factor to be applied to the UERE to obtain the corresponding three-dimensional position error. It is calculated from the horizontal and vertical DOP according to

$$\text{PDOP} = \sqrt{\text{HDOP}^2 + \text{VDOP}^2} \quad \text{Eq. 8}$$

- The Time DOP (TDOP) is the scale factor to be applied to the ranging measurement error to obtain the corresponding time offset determination error (with respect to the particular system's reference timescale).

$$\text{TDOP} = \sqrt{\sigma_t^2} \quad \text{Eq. 9}$$

- Geometric DOP (GDOP) includes by definition both the position and time DOP, according to

$$\text{GDOP} = \sqrt{\text{PDOP}^2 + \text{TDOP}^2} \quad \text{Eq. 10}$$

Additionally, the TTDOP can be distinguished:

- The Time Transfer DOP (TTDOP) is the scale factor to be applied to the UERE to obtain the time offset determination error (with respect to the particular system's reference timescale) for timing users at a known location.

$$\text{TTDOP} = \sqrt{1/n_{SV}} \quad \text{Eq. 11}$$

where  $n_{SV}$  is the number of healthy Galileo signals in space used by the receiver.

Because the DOP depends exclusively on the relative geometry between user equipment and the tracked satellites, it is completely deterministic and predictable under certain assumptions, namely:

- Knowledge of the approximate user and transmitter locations at the desired time in the future.
- The user's sky visibility conditions or masking angle above the horizon.

#### C.4.5.3. STATISTICAL MODELLING OF THE PVT ACCURACY

This section provides the derivation of the position and timing accuracy performance based on the definitions of UERE and DOP in the previous sections.

The basic equations for position errors, i.e. Horizontal Error, Vertical Error and Time (Transfer) Error based on UERE definition and DOP factors are:

$$\text{HE}(rms) = \text{UERE} \cdot \text{HDOP}$$

$$\text{VE}(rms) = \text{UERE} \cdot \text{VDOP}$$

Eq. 12

$$\text{T(T)E}(rms) = \frac{\text{UERE}}{c} \cdot \text{T(T)DOP}$$

This approximation for the position errors can be used under the assumption of zero mean and normally distributed pseudorange errors characterised by identical UERE for every pseudorange.

## C.4.6 USER TOTAL UNCERTAINTY IN UTC TIME ESTIMATION

Table 18 shows the Availability of the Galileo UTC Time Determination Accuracy, i.e., the system only component to the overall uncertainty in the UTC time estimation performed by users.

As introduced in section 2.3.3.1, non-system contributions should also be considered in the estimation of the overall user UTC time transfer accuracy. This can be achieved using the following equation

$$UUTCE = \sqrt{\left(\frac{UERE \cdot T(T)DOP}{c}\right)^2 + UTCDE^2} \quad \text{Eq. 13}$$

where

- UUTCE = User UTC SIS Error (rms)
- T(T)DOP = Time (Transfer) Dilution of Precision
- UTCDE = UTC SIS dissemination error (system only contribution).

## C.4.7 IONOSPHERIC DELAY MODEL FOR GALILEO SINGLE-FREQUENCY USERS

The ionospheric delay model for Galileo single-frequency users is the *NeQuick* model described in (Annex A [2]). The Galileo navigation message includes several parameters that are used by receivers implementing the *NeQuick* model to compute the ionospheric effect in order to be able to apply the corresponding corrections.

## C.4.8 SINGLE-FREQUENCY GROUP DELAY TIME CORRECTION ERRORS

A single-frequency user receiver must apply the Broadcast Group Delay (BGD) corrections to the SV clock following the equations described in the Galileo OS SIS ICD (Annex A [1]). Errors in the BGD values affect the SISE experienced by the single-frequency users.

As an example, the UERE budget illustrated for the single-frequency E1 - Rural Pedestrian (RP) in Table 24 also includes a typical BGD error contribution.

## C.5. INTEGRITY

The characterisation of Galileo service in terms of integrity is an on-going activity. This section will be developed in future issues of the document.

## C.6. CONTINUITY

The characterisation of Galileo service in terms of continuity is an on-going activity. This section will be developed in future issues of the document.

Superseded



ANNEX D:  
GALILEO OPEN  
SERVICE – PERFORMANCE  
EVOLUTION AND  
ADDITIONAL PERFORMANCE  
PARAMETERS

## D.1. INTRODUCTION

### D.1.1 SCOPE

The main body of this Galileo OS SDD focuses on the Minimum Performance Levels provided by the Galileo OS at the time of publication. This annex provides complementary information about the expected performance levels and their evolution during deployment of the system and until its completion at FOC as well as the expected values of other performance parameters. The expected values of each performance parameter are provided in this Annex as a function of the number of operational satellites in the Galileo constellation. The values of the performance parameters reported in this Annex for the reference constellation described in Section 3.2 are typical expected values.

### D.1.2 LIMITATIONS

The information in this Annex is provided exclusively for reference and does not in any way affect the MPLs presented in section 3 of this OS SDD.

### D.1.3 GALILEO CONSTELLATION EXPECTED EVOLUTION

In Table 8, the Galileo constellation considered as reference in the preparation of this OS SDD is provided. The evolution of the expected values of the performance parameters presented in the following sections assumes three deployment stages with respectively 18, 22 and 24 operational satellites. Details of the final constellation of 24 satellites can be found in section C.2.

## D.2. GALILEO SIS RANGING ACCURACY EVOLUTION OF EXPECTED SISE

As explained in section 2.3.2.1, the Galileo OS Ranging Accuracy is defined as a statistic of the Galileo SIS Ranging Error (SISE), which is the SIS portion of the GNSS error budgets to the user equivalent range error (UERE) and comprises all effects originating from and/or controlled by the Galileo system while user local effects and atmospheric effects (ionospheric/tropospheric) are not included. The Galileo SISE is driven by the error of the broadcast ephemeris and clock correction parameters. The accuracy in the estimation of these values depends mainly on the number of observables, i.e. ranging measures, available to the algorithms implemented in the Ground Segment that computes such values. For this reason, the increase of the number of operational satellites in a GNSS constellation implies an improvement of the determination of the broadcast ephemeris and clock correction parameters and therefore of the SIS ranging accuracy until a certain number of operational satellites is reached. Further satellites will result in an increased availability of the services provided, but not in a further improvement of the ranging accuracy.

The Galileo constellation has already reached this situation, with an expected typical worst-case SISE indicated in Table 26<sup>18</sup>

SERVICE	TYPICAL SISE	
SF	E1	1.45
	E5a, E5b	1.75
DF	any combination	1.3

Table 26. Typical Galileo SIS Ranging Accuracy (WUL, in metres, 95%).

18.... This table provides two separate values for the Single Frequency Galileo SIS Ranging Accuracy in E1 and in E5a, E5b. The respective Table in the OS SDD V1.0 only showed the case of E1. Note that the difference between the SF performance in E1 compared to the SF performance in E5a and E5b is due to the different characteristics of the Broadcast Group Delay (BGD) corrections (C.4.8).

## D.3. EVOLUTION OF THE EXPECTED AVAILABILITY OF GLOBAL PDOP

In this section, values are provided for the evolution of the expected Availability of Global PDOP, as a function of the number of operational healthy satellites (Table 27). The Availability of PDOP is computed at any user location as the percentage of time at least 4 Galileo satellites, transmitting healthy SIS, are in view above a minimum elevation angle of 5 degrees, and with a threshold of  $PDOP \leq 6$  to identify sufficiently good local geometries. The Availability of Global PDOP is specified for the average user location (AUL) within the service coverage, i.e. computed as the average over all user locations (see section C3.3 for the definition of service coverage) and for the worst user location (WUL). Note that when all 24 slots of the nominal constellation are occupied by satellites broadcasting healthy SIS, the availability of  $PDOP \leq 6$  will be 100% at any user location.

PDOP $\leq 6$	NUMBER OF SATELLITES		
	18	22	24
AUL	90%	95%	99.78%
WUL	84%	95%	99.78%

Table 27. Evolution of the Expected Availability of Global PDOP.

## D.4. EVOLUTION OF THE EXPECTED GALILEO OS POSITIONING PERFORMANCE

This section of Annex D presents how the expected positioning performance of the Galileo OS will evolve with the deployment of the system until the FOC is reached.

### D.4.1 EVOLUTION OF THE GALILEO OS POSITIONING SERVICE EXPECTED ACCURACY

As explained in Annex C, the Galileo system, the signal propagation channel and the user equipment all contribute to the positioning accuracy experienced by the Galileo users. Although in the main part of this document all contributions to the performance of Galileo that are not under control of the system are not considered, in this Annex such contributions are considered so that it is possible to indicate the global average positioning performance and WUL performance that a Galileo only user can expect to experience.

Specifically, Table 28 presents the evolution of the horizontal and vertical expected position accuracy for the Galileo OS Positioning versus the number of operational healthy satellites, using the UERE values shown in Table 24 and Table 25. The values provided, which take into account the constraint of geometrical  $PDOP \leq 6$ , represent the accuracy users would expect if they would measure their position over one complete constellation repeat cycle, from the worst user location and from the average user location.

SPATIAL STATISTICS	SERVICE		NUMBER OF SATELLITES		
			18	22	24
AUL	DF	H	2.3	1.8	1.5
		V	3.5	2.9	2.6
	SF	H	11.3	8.7	7.6
		V	17.2	14.0	12.8
WUL	DF	H	2.7	1.9	1.7
		V	3.8	3.3	3.0
	SF	H	13.4	9.5	8.2
		V	18.7	16.2	15.0

Table 28. Evolution of the Expected Galileo OS Positioning Performance in nominal configuration (in metres, 95% values).

## D.4.2 EVOLUTION OF THE GALILEO OS POSITIONING SERVICE EXPECTED AVAILABILITY

Full deployment of the Galileo system will also imply an increase of the OS Positioning Service Availability.

The Availability of DF and SF Positioning for OS is computed at any user location as the percentage of time with a DF and respectively SF positioning error less than or equal to a specific value, considering only healthy Galileo SIS from satellites above a minimum elevation angle of 5 degrees, for the average user location within the service coverage (i.e. computed as the average over all user locations, see section C3.3 for the definition of service coverage). The Availability of DF and SF Positioning are provided as monthly values. Table 29 presents the typical Availability of DF and SF Positioning for OS and its expected evolution versus the number of operational healthy satellites. The values provided are global average values. For the full constellation the value represents the expected availability of Open Service over the full lifetime of the Service, including degraded constellation configurations.

SERVICE			NUMBER OF SATELLITES		
	Horizontal Accuracy (95%)	Vertical Accuracy (95%)	18	22	24
DF	≤ 4m	≤ 8m	86%	95%	99.5%
SF	≤ 15m	≤ 35m	80%	94%	99.5%

Table 29. Typical Galileo OS Positioning Service Availability (global average) and expected evolution.

## D.5. ADDITIONAL PERFORMANCE PARAMETERS

This section of Annex D presents additional performance parameters to those described in the main body of the document. The aim is to provide a further insight in the performance of the Galileo service, beyond the parameters for which the MPLs apply.

These parameters, therefore, are provided exclusively for reference and their values do not constitute any MPL expected to be met by any service.

## D.5.1 ADDITIONAL PARAMETERS FOR GALILEO OS RANGING ACCURACY

Table 26 in Section D.2 shows the expected Galileo OS Ranging Accuracy as ranging performance at the 95th percentile evaluated over all AOD, following the definition provided for the respective MPL in Section 2.3.2.1.

In this section, the expected values of other performance parameters characterising further the Galileo OS Ranging Accuracy are provided: the ranging accuracy at higher percentile and the ranging accuracy at any AOD.

### D.5.1.1. GALILEO OS RANGING ACCURACY AT HIGHER PERCENTILE

In order to account for more rare events that might affect the provision of the ranging service, the current typical Galileo OS Ranging Accuracy is provided in Table 30 at 99.9% of time, for the constellation average and the worst case, i.e. for any healthy SIS, both at the worst user location. These statistics are computed on a yearly basis.

SPATIAL STATISTICS	SERVICE	GALILEO OS RANGING ACCURACY AT 99.9% OF TIME
Constellation average	DF	2.5 m
	SF	2.5 m
For any healthy OS SIS	DF	10 m
	SF	10 m

Table 30. Typical Galileo OS Ranging Accuracy performance calculated at 99.9% of time (on yearly basis).

### D.5.1.2. GALILEO OS RANGING ACCURACY DEPENDENCE ON AOD

As explained in Section C.4.4, the accuracy of the orbit and clock models, and therefore of the ranging accuracy provided by a certain SIS, degrades with increase AOD.

The definition of ranging accuracy used in in Section 2.3.2.1 for the MPL considers that the SISE time series used for the calculation of the performance will consider the navigation message at the age of data when it was observed. This approach “over all AOD” resembles closely the real conditions experienced by a user that will receive various navigation messages from the different Galileo satellites in view, each one with its own AOD.

Nonetheless, specific assumptions can be made concerning the value of the AOD in order to provide more conservative expected values of the ranging accuracy, to further characterise Galileo performance, for example, the Galileo OS Ranging Accuracy at the worst AOD.

The Galileo OS Ranging Accuracy at the worst AOD is calculated when the accuracy of the orbit and clock models provided by the navigation message is the lowest which leads to obtaining the worst ranging accuracy performance. The expected Galileo OS Ranging Accuracy at the worst AOD is provided in Table 31 for any satellite.

GALILEO SIS RANGING ACCURACY EXPECTED VALUE FOR ANY SATELLITE	CONDITIONS AND CONSTRAINTS
For each SF: <ul style="list-style-type: none"> <li>• <math>\leq 20</math> m (95%) global average, worst AOD</li> </ul>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• For any healthy OS SIS above a minimum elevation angle of 5 degrees</li> <li>• Including Broadcast Group Delay errors</li> <li>• Propagation and user contributions excluded</li> <li>• Neglecting single frequency ionospheric delay model errors</li> </ul>
For each DF combination: <ul style="list-style-type: none"> <li>• <math>\leq 20</math> m (95%) global average, worst AOD</li> </ul>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• For any healthy OS SIS above a minimum elevation angle of 5 degrees</li> <li>• Propagation and user contributions excluded</li> </ul>

Table 31. Galileo OS SIS Ranging Accuracy typical values for any satellite at the worst AOD

## D.5.2 PARAMETERS RELEVANT TO SAFETY-OF-LIFE APPLICATIONS

In order to support the use of Galileo Open Service for Safety-of-Life (SoL) applications for aviation (e.g SBAS, ARAIM, GBAS, etc), certain information about the Galileo system is required. A work plan agreed at Galileo Programme level is currently on-going to identify, define and characterise the Galileo performance parameters required by SoL users.

In this Annex D, initial information is provided about two of these parameters: the probability of constellation fault ( $P_{\text{const}}$ ) and the probability of signal in space fault ( $P_{\text{sat}}$ ).

### D.5.2.1. PROBABILITY OF CONSTELLATION FAULT ( $P_{\text{const}}$ )

The  $P_{\text{const}}$  describes the probability that at any given time, for any user in the satellite visibility area, and due to a common cause, any subset of two or more satellites within Galileo operational constellation provides an instantaneous SIS ranging error (SISE) higher than a predefined threshold without notification sent to the user, i.e. with the SIS flagged as Healthy. One example of this kind of event is the broadcast by multiple satellites of incorrect navigation data due to a common cause originating at the GNSS ground segment.

The expected value of the Galileo  $P_{\text{const}}$  for future configurations of Galileo during the FOC service provision phase is reported in Table 32.

GALILEO EXPECTED PROBABILITY OF CONSTELLATION FAULT	CONDITIONS AND CONSTRAINTS
$P_{\text{const}} = 1 \times 10^{-4}$	SISE Threshold = 40 m

Table 32. Galileo probability of constellation fault (expected value for future configurations of Galileo during the FOC service provision phase).

### D.5.2.2. PROBABILITY OF SIS FAULT ( $P_{sat}$ )

The  $P_{sat}$  describes the probability that, at any given time, for any user in the satellite visibility area, one satellite of Galileo operational constellation provides an instantaneous SISE (see section 2.3.2.1) higher than a predefined threshold, without notification sent to the user, i.e. with the SIS flagged as Healthy. This faulty situation can be caused, for example, by erroneous satellite navigation data or anomalous satellite payload events.

The expected value of the Galileo  $P_{sat}$  for future configurations of Galileo during the FOC service provision phase is reported in Table 33.

GALILEO EXPECTED PROBABILITY OF SIS FAULT	CONDITIONS AND CONSTRAINTS
$P_{sat} = 6 \times 10^{-5}$	SISE Threshold = 40 m

Table 33. Galileo probability of satellite fault (expected value for future configurations of Galileo during the FOC service provision phase).

### D.5.3 ACCURACY OF ALMANAC

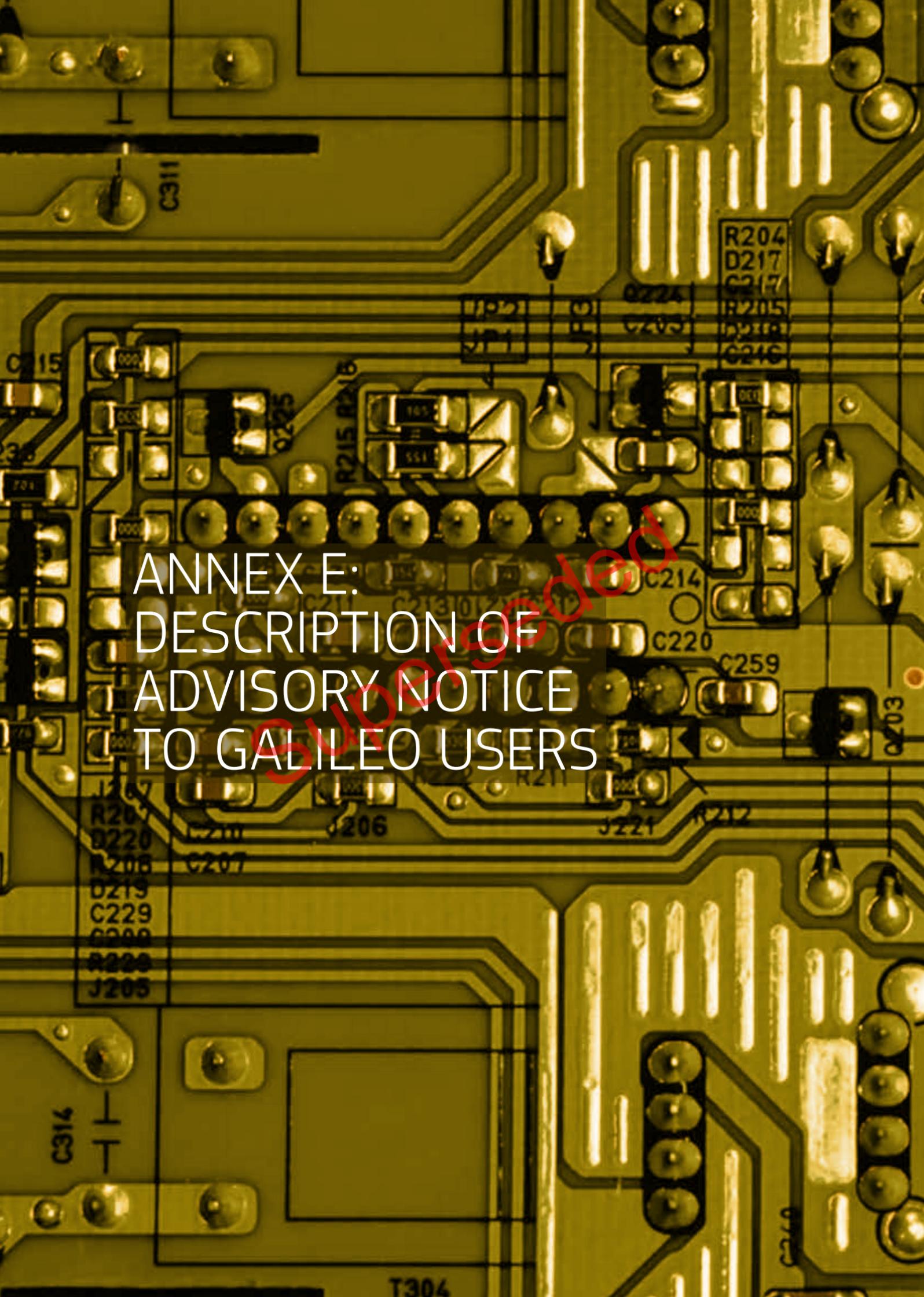
As explained in the OS SIS ICD (Annex A [1]), the almanac is a reduced-precision subset of the clock and ephemeris parameters and predicted SIS health status of the satellites in orbit.

The scope of the almanac is to indicate the position of all the satellites in the constellation with a reduced accuracy in order to facilitate the Galileo signal acquisition.

In Table 34, the typical Galileo OS Ranging Accuracy 95% is provided in case only the clock and ephemeris information retrieved from the Galileo almanac is used, instead of the information from the broadcast navigation message. The typical values using 12 hour old and 24 hour old almanac information are provided.

GALILEO SIS RANGING ACCURACY EXPECTED VALUE OVER ALL SATELLITES	CONDITIONS AND CONSTRAINTS
<p>For each SF:</p> <ul style="list-style-type: none"> <li>• <math>\leq 860</math> m, at 12 hours</li> <li>• <math>\leq 1400</math> m, at 24 hours</li> </ul> <p>Global Average</p>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• Average, over the constellation, of the Galileo SIS Ranging Accuracy (95%) of each Healthy SIS</li> <li>• Using almanac's clock and ephemeris information</li> </ul>
<p>For each DF combination:</p> <ul style="list-style-type: none"> <li>• <math>\leq 860</math> m, at 12 hours</li> <li>• <math>\leq 1400</math> m, at 24 hours</li> </ul> <p>Global Average</p>	<ul style="list-style-type: none"> <li>• Calculated over a period of 30 days</li> <li>• Average, over the constellation, of the Galileo SIS Ranging Accuracy (95%) of each Healthy SIS</li> <li>• Using almanac's clock and ephemeris information</li> </ul>

Table 34. Galileo SIS Ranging Accuracy typical values over all satellites, Global Average, when almanac's clock and ephemeris information is used.



ANNEX E:  
DESCRIPTION OF  
ADVISORY NOTICE  
TO GALILEO USERS

## E.1. NAGU FORMAT

This section of the Annex describes the format of the NAGUs issued to Galileo users through the European GNSS Service Centre web portal.

Two types of NAGU can be issued:

- Specific NAGUs
- General NAGUs.

### E.1.1 SPECIFIC NAGU

Specific NAGUs follow the format defined below:

NOTICE ADVISORY TO GALILEO USERS (NAGU)	YYYYNNN
DATE GENERATED (UTC):	YYYY-MM-DD hh:mm
NAGU TYPE:	AS PER NAGU DEFINITION
NAGU NUMBER:	YYYYNNN
NAGU SUBJECT:	AS PER NAGU TEMPLATE
NAGU REFERENCED TO:	YYYYRRR OR N/A
START DATE EVENT (UTC):	YYYY-MM-DD hh:mm
END DATE EVENT (UTC):	YYYY-MM-DD hh:mm OR N/A
SATELLITE AFFECTED:	SATELLITE_NAME
SPACE VEHICLE ID:	SVID
SIGNAL(S) AFFECTED:	E1, E5a, E5b, E6, E6-B, E6-C OR ALL
EVENT DESCRIPTION:	AS PER NAGU TEMPLATE

### E.1.2 GENERAL NAGU

General NAGUs follow a simplified version of the format used for specific NAGUs, providing additional flexibility on the definition of the subject (e.g. launch, validation campaigns, status flags, etc.):

NOTICE ADVISORY TO GALILEO USERS (NAGU)	YYYYNNN
DATE GENERATED (UTC):	YYYY-MM-DD hh:mm
NAGU TYPE:	GENERAL
NAGU NUMBER:	YYYYNNN
NAGU SUBJECT:	FREE TEXT
NAGU REFERENCED TO:	YYYYRRR OR N/A
START DATE EVENT (UTC):	YYYY-MM-DD hh:mm
END DATE EVENT (UTC):	YYYY-MM-DD hh:mm OR N/A
SATELLITE AFFECTED:	SATELLITE_NAME OR ALL
EVENT DESCRIPTION:	FREE TEXT

### E.1.3 DESCRIPTION OF NAGU'S CONTENT

The fields used within the specific and general NAGUs are defined as follows:

- 1) **HEADER:** The first line of the text field refers to the title "NOTICE ADVISORY TO GALILEO USERS" (NAGU), followed by the NAGU number in the format YYYYNNN, where:
  - **YYYY:** Gregorian year.
  - **NNN:** sequential number of the NAGU, starting with 001 on the 1st of January every year and incrementing by 1 for each subsequent NAGU.
- 2) **DATE GENERATED (UTC):** The date when the NAGU is generated on the GSC web portal, in UTC time scale with format YYYY-MM-DD hh:mm, where:
  - **YYYY:** Gregorian year.
  - **MM:** number of the month from 1-12 in sequence starting with 1 being January, and finishing with 12 being December.
  - **DD:** day within the Gregorian month
  - **hh:** hour in the 24 hour format
  - **mm:** minute

- 3) **NAGU TYPE:** The different NAGU types as defined in Annex E.2.
- 4) **NAGU NUMBER:** Reference to the NAGU number in the format YYYYNNN (as defined in the Header field).
- 5) **NAGU SUBJECT:** The subject of the NAGU summarising the information provided in the "Event Description". The text to be used in the subject is defined by the template of each NAGU. For GENERAL NAGU, this is a free text description.
- 6) **NAGU REFERENCED TO:** If the current NAGU refers to a previous NAGU, this field contains the referenced NAGU number in the format YYYYRRR, where:
  - **YYYY:** Gregorian year when the NAGU was issued.
  - **RRR:** issue number of the NAGU for that year.

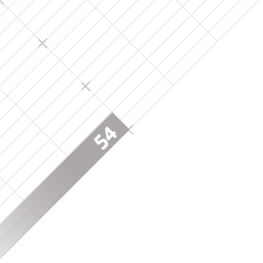
Otherwise, the field contains N/A (not applicable) when there is no reference to a previous NAGU.
- 7) **START DATE EVENT (UTC):** The start date of the event notified by the NAGU, in UTC time scale with format YYYY-MM-DD hh:mm.
- 8) **END DATE EVENT (UTC):** The end date of the event notified by the NAGU, in UTC time scale with format YYYY-MM-DD hh:mm.
- 9) **SATELLITE AFFECTED:** The name of the satellite affected (GSAT, Galileo SATEllite). For GENERAL NAGU, this field contains ALL to indicate that all satellites are affected.
- 10) **PACE VEHICLE ID:** The Space Vehicle ID (SVID) of the satellite affected. This field is not present in the GENERAL NAGU.
- 11) **SIGNAL(S) AFFECTED:** The signal(s) affected by the satellite indicated in the NAGU. The signals affected can be one or a combination of the following: E1, E5a, E5b, E6, E6-B, E6-C or ALL. Partial outage/availability of the signals is indicated in the NAGU subject if ALL signals are not affected. This field is not present in the GENERAL NAGU.
- 12) **EVENT DESCRIPTION:** The event description following the templates defined for each NAGU.

## E.2. LIST OF DEFINED NAGUS

This section of the Annex describes the different NAGUs that are defined and that can be issued to the Galileo users through the GSC web portal.

NAGU TYPE (ABBREVIATION)	NAGU TYPE	NAGU DESCRIPTION
PLN_MANV	Planned manoeuvre	Planned activity affecting the attitude and/or orbit. The planned outage start and end times due to manoeuvre operation are indicated.
PLN_OUTAGE	Planned outage	Planned activity (space or ground segment) that causes an outage of the satellite SIS broadcasted. The planned outage start and end times are indicated.
AVAILINIT	Satellite first time available	The satellite is for the first time providing healthy SIS following completion of satellite in-orbit commissioning activities. The type of clock being used to drive the navigation payload is also indicated. Satellite is not yet contributing to service provision.
USABINIT	Satellite first time usable	The satellite is for the first time providing signals and navigation messages according to the service performance commitment. The type of clock being used to drive the navigation payload is also indicated. Satellite enters into service and contributing to service provision.

NAGU TYPE (ABBREVIATION)	NAGU TYPE	NAGU DESCRIPTION
AVAILABLE	Available for testing	The satellite starts transmitting healthy SIS following the end of a planned outage or recovery of an unplanned outage. The exact outage start and end times are indicated. The type of clock being used to drive the navigation payload is also indicated. This NAGU type is used prior to Service Declaration.
USABLE	Usable for service provision	The satellite starts transmitting healthy SIS following the end of a planned outage or recovery of an unplanned outage. The exact outage start and end times are indicated. The type of clock being used to drive the navigation payload is also indicated. This NAGU type is used following Service Declaration.
PLN_CANCEL	Cancellation	Cancellation of published NAGUs.
PLN_RESCH	Reschedule	Provision of new start/end times for published planned NAGU.
PLN_EXTNS	Extension	Provision of new end time for published planned NAGU or notification of the planned outage end time for published unplanned NAGU (UNP UNUFN).
DECOMMSNG	Satellite decommissioned	Commencement of satellite decommissioning phase.
UNP_UNUFN	Unavailable until further notice	Unscheduled outage of the satellite SIS broadcasted of undefined duration.
UNP_SHTRCVR	Short term outage recovered	Events (short term) that have been recovered before a NAGU could be published.
GENERAL (NOTICE)	General notice	General notifications such as announcing the IOV campaign, Service validations, announcement of Service declarations, introduction of services, IOC, FOC, etc.
GENERAL (LAUNCH)	Launch	Notification of the satellite launch.
GENERAL (LEAP SECOND)	Leap second	Notification of leap second adjustment.
GENERAL (TIMING PLN_OUTAGE)	Planned outage timing services	Notification of a planned operation entailing an outage of timing services.
GENERAL (TIMING AVAILABLE)	Availability of timing services	Notification of availability of timing services following the end of a planned operation/ recovery of an unplanned outage with impact related only to timing services.
GENERAL (TIMING PLN_CANCEL)	Cancellation of planned outage timing services	Cancellation of published general NAGU notification for a planned operation entailing an outage of timing services.
GENERAL (TIMING PLN_RESCH)	Reschedule of planned outage timing services	Provision of new start/end times for published general NAGU notification for a planned operation entailing an outage of timing services.
GENERAL (TIMING PLN_EXTNS)	Extension of planned outage timing services	Provision of new end time for published planned NAGU.
GENERAL (TIMING UNP_UNUFN)	Unplanned outage timing services	This general NAGU provides notification of an unplanned outage related with timing services.
GENERAL (TIMING UNP_SHTRCVR)	Short term outage timing services	This general NAGU provides notification of short term timing services outage that have been recovered before a NAGU could be published.



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