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SIGNAL-IN-SPACE OPERATIONAL STATUS DEFINITION

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DOCUMENT CHANGE RECORD

REASON FOR CHANGE	ISSUE	REVISION	DATE
First version to support Public Consultations on the OS SIS OSD	1	0	September 2015
First Public Issue of the OS SIS OSD	1	1	July 2016

SECTION 1: INTRODUCTION

1.1 BACKGROUND

Galileo is the European Global Navigation Satellite System (GNSS), providing a highly accurate and global positioning service under civilian control. Galileo, and in general current GNSS, are based on the broadcasting by satellite of electromagnetic ranging signals in the L frequency band. The performance achievable through Galileo in terms of position, velocity and time determination accuracy depends on the availability of a number of such signals, uncorrupted and compliant with the system specifications. In order to enable Galileo receivers to properly handle each signal, the signal itself, within the associated Navigation Message, contains information about its operational status.

Because of the inherent complexity of a Global Navigation Satellite System, the quality of Galileo signals depends on a wide variety of factors. Nonetheless, the status of signals has been encoded using a minimal set of parameters that receivers can extract and decode in order to determine the status of each signal.

1.2 DOCUMENT SCOPE

This document complements the Galileo Open Service Signal-In-Space Interface Control Document (OS SIS ICD, ref. Annex A[1]) by describing the encoding and use of the European GNSS Signal-In-Space (SIS) Status for the Galileo Open Service (OS). The SIS Status (i.e. the operational status of the OS SIS broadcast by each of the Galileo satellites) is an important parameter whose value determines the applicability of the Minimum Performance Level of services (hereinafter the “Minimum Performance Level” or MPL) as described by the Service Provider in the Galileo Open Service – Service Definition Document (OS-SDD), which will be published before the Galileo OS is declared available.

The content of this document is specifically targeted towards manufacturers of Galileo receivers. The first part provides a comprehensive guide of how the status of the Galileo SIS is disseminated by the signal itself through specific data within the Navigation Message. In the second part, some considerations about the use of navigation parameters are presented and the reference for the ionospheric model used by Galileo is recalled. Finally, in the last chapter, some considerations are provided concerning the validity of navigation parameters.

SECTION 2: GALILEO OPEN SERVICE SIS STATUS

2.1 SIS STATUS

Users of the Galileo Open Service (OS) can obtain information about the Signal-In-Space (SIS) Status, i.e. about the operational status of the OS SIS [1] broadcast by each one of the Galileo satellites, through the signals themselves.

The Galileo SIS Status can assume 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 [2].
- SIS "Unhealthy": The SIS is out of service or under test.
- SIS "Marginal": The SIS is in neither of the two previous statuses.

The Galileo OS Minimum Performance Levels reported in the future Galileo OS SDD will refer exclusively to Healthy SIS. No MPL is defined for Unhealthy or Marginal SIS.

2.2 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 and by a specific type of message that may replace the standard one: the so called dummy message (see section 2.2.1).

The purpose, structure and content of the Galileo navigation message are explained in the Galileo Open Service Interface Control Document (OS SIS ICD, Annex A[1]). As detailed there, the complete navigation message data is 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.

In the context of this document, by "navigation message" a sub-frame is meant (50 seconds for F/NAV and 30 seconds for I/NAV) that contains ephemeris and clock corrections or SIS health information, i.e. Page Type 1 to 4 for the F/NAV and Word Type 1 to 6 for the I/NAV.

2.2.1 DUMMY MESSAGE

When no valid navigation data is to be transmitted by a satellite, dummy pages are generated and downlinked. 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 the whole navigation message which is then defined as a dummy navigation message.

A dummy navigation message indicates Unhealthy SIS. Therefore, as soon as a dummy page, i.e. Page/ Word Types 63, is decoded, 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 use the SIS again.

Note that in the case of Dual Frequency (DF) users, a dummy navigation message on either of the frequencies implies that the DF service is not Healthy (see also section 2.3) [3].

2.2.2 SIS STATUS FLAGS

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

1. *The Galileo OS SIS comprises signals broadcast on the E1B, E5a, and E5b carriers (see the OS SIS ICD, for more details).*
2. *Note that this assertion does not apply to the Minimum Performance Level for the provision of the GPS-Galileo System Time Offset (GGTO). Healthy SIS can broadcast parameters that indicate a non-valid GGTO (ref. Annex A[1] for more details about the dummy value of the GGTO parameters).*
3. *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.*

Annex A[1] for the complete definitions of the different flags):

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

The mapping of the SIS Status with the SIS Status flags is provided in section 2.3.

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 should not be used operationally to determine the SIS Status.

The SHS flag can be raised by the system at any moment [4]. The SHS flags can assume the values defined in the OS SIS ICD (Annex A[1]), and recalled for convenience in Table 1.

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 1. 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 2.

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

Table 2. Data Validity Status Bit Values

The DVS flag can be triggered in two ways:

1) When the time passed since the last navigation message uplink to the satellite is greater than a predefined threshold.
2) By the satellite in case of certain anomalies.

In the first case, the DVS acts as a timer accounting for the age of the navigation message. The time interval threshold for its triggering is set by the system to ensure the service performance.

In the second case, as the DVS is triggered on-board in case of specific events, meaning that the DVS flag value can change at any time [5].

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, (Annex A[1]), the SISA parameter can assume 255 values. Nonetheless, 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≠255). Note that the 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 3.

SISA INDEX	SISA VALUE
255	No Accuracy Prediction Available (NAPA)
0……254	not NAPA

Table 3. SISA Index values relevant to the assessment of the SIS Status

4……*The Time To Alert between the occurrence of an event and the setting of the SHS is under definition. When available, the related performance will be provided through the OS SDD.*

5……*The Time To Alert between the occurrence of an event and the setting of the DVS is under definition. When available, the related performance will be provided through the OS SDD.*

2.3 MAPPING BETWEEN SIS STATUS FLAGS AND SIS STATUS

The mapping between the values of the SIS Status Flags and the three values of the SIS Status is provided in Table 4.

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 4. Galileo Open Service SIS Status vs SIS Status flags

In order to determine the Status of a specific SIS broadcast by a Galileo satellite, the user will have to ensure that the navigation message has been properly received, i.e. that it successfully passes the CRC check (see section 2.3.1).

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 cannot be a dummy message. As explained in section 2.2.1, if it is a 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 4. The order in which the flags are checked by a receiver on a not 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 example of a possible decision tree for the determination of the SIS Status is provided in Figure 1.

As an example of receiver operations, in section 2.2.2 it is explained that the DVS flag could be set to WWG in case the respective SIS cannot be considered Healthy but, depending on the value of the other flags, only Marginal. This means that neither the SIS nor any of the parameters obtained through such SIS should be used. 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 Healthy, they will have to retrieve the most recent navigation data set newly broadcast in order to use such SIS.

In other words, all the parameters requested by a receiver have to be retrieved once the SIS is (back to) Healthy in order to ensure that the MPL is expected to be met.

Note also that the value of SIS Status flags applies to the whole subframe 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 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 5 shows the summary of the SIS Status Flags to be checked by the different Galileo OS users for both SF and DF services

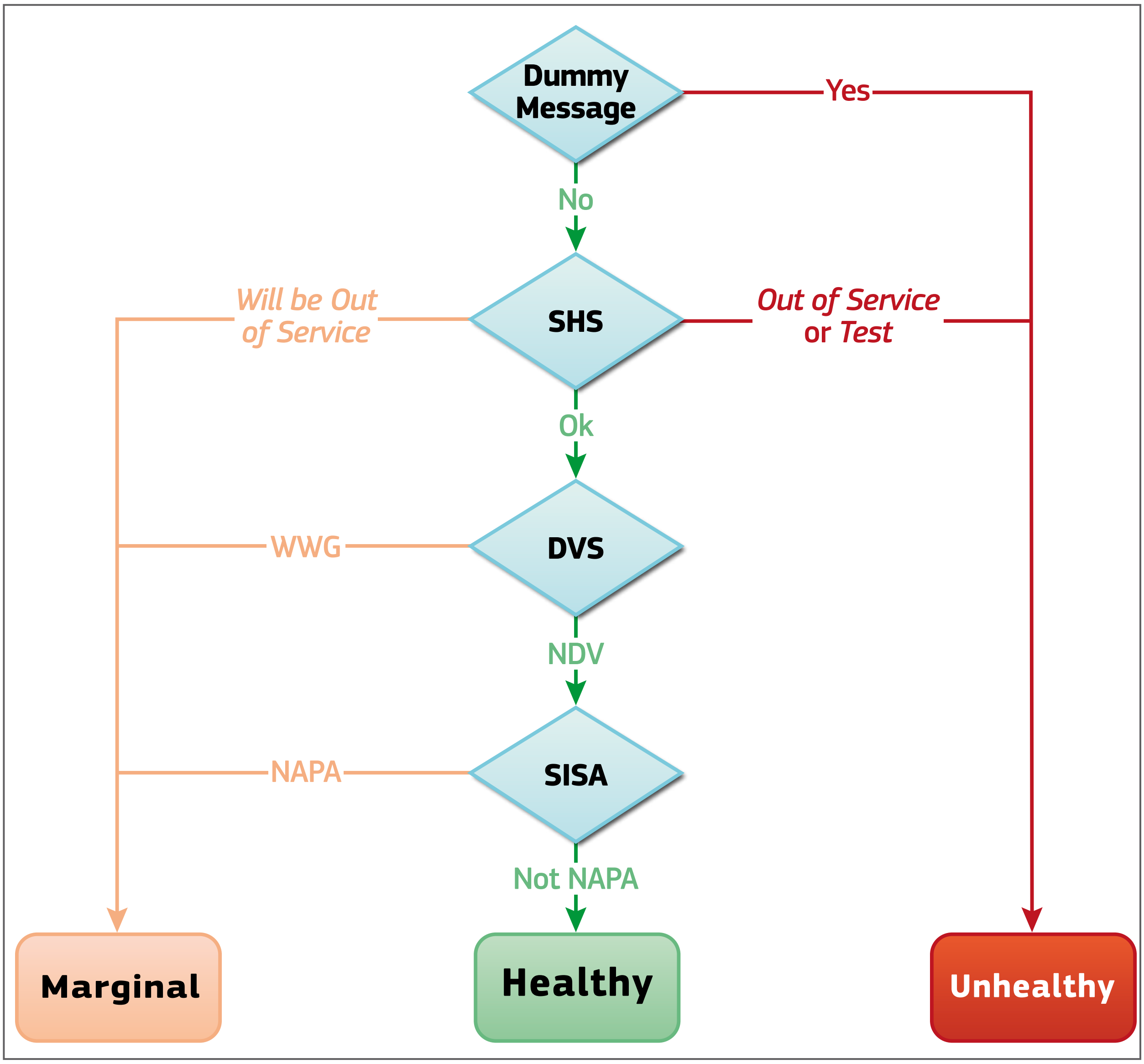


Figure 1. Example of a decision tree for the determination of the SIS Status

USERS		F/NAV			I/NAV					
		$E5a_{HS}$	$E5a_{DVS}$	SISA(E1,E5a)	$E1B_{HS}$	$E1B_{DVS}$	$E5b_{HS}$	$E5b_{DVS}$	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 5. Summary of SIS flags to be checked by the different Galileo OS users to compute the Status of Signals-In-Space

2.3.1 ON THE MEANING OF THE CYCLIC REDUNDANCY CHECK (CRC)

To detect the corruption of the received data a checksum is used by the Galileo navigation message, which employs 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, i.e. on transmitter side. The CRC checksum is exclusively related 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 available 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 is rejected and no determination of the SIS Status is possible. Once a navigation message is finally received with a successful CRC, the user can then proceed to the SIS Status determination, as described in the previous section, and eventually to the utilisation of such SIS.

SECTION 3: NAVIGATION PARAMETERS AND 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). The identification of each batch by an IOD value enables:

- the users to distinguish the data in different batches received from each satellite;
- to indicate to the user's receiver the validity of the data (which have to be updated using new issue of navigation data);
- 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 almanacs.

Another set of navigation data, the broadcast group delay (BGD), ionospheric corrections, GST-UTC and GST-GPS Time conversion parameters, navigation data validity status (DVS) and signal health status (SHS), is not identified by any Issue of Data.

3.1 USAGE OF PARAMETERS IDENTIFIED BY AN IOD VALUE

To compute position and clock corrections, receivers must use, for each satellite, IOD-tagged parameters corresponding to the same IOD Value. These parameters must be retrieved from the most recent navigation data set broadcast on a Healthy SIS by the Galileo system after the start of the current receiver operation. These are the two conditions 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.

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 indeed 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.

3.2 USAGE OF PARAMETERS NOT IDENTIFIED BY AN IOD VALUE

As mentioned in section 3, the BGD, ionospheric corrections, GST-UTC and GST-GPS conversion parameters, DVS and SHS are not identified by an IOD Value.

As is the case for IOD-tagged parameters, to compute the navigation solution, receivers must retrieve the values of not IOD-tagged parameters relevant to the type of navigation solution to be computed [6] 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 under which the navigation solution is expected to meet the Minimum Performance Level.

The satellite specific parameters (BGD, DVS, SHS) have to be obtained 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.

6....... As an example, DF users do not need to retrieve ionospheric parameters

SECTION 4:
IONOSPHERIC MODEL

The ionospheric delay is usually the largest contributor to the pseudorange error for single-frequency users. This delay can be partially mitigated using ionospheric models such as Klobuchar or *NeQuick*. The ionospheric model adopted by Galileo is the *NeQuick* model (Annex A[2]). The Galileo navigation message includes several parameters that are used by receivers implementing the *NeQuick* model to compute the ionospheric effect.

SECTION 5: VALIDITY OF NAVIGATION PARAMETERS

The navigation dataset refresh rate is a parameter defined by the system. The typical refresh rate of the navigation data set through upload from Galileo Ground Segment to satellites can range from a minimum of 10 minutes to about 3 hours.

Navigation parameters shall not be used beyond the maximum possible broadcast period of a healthy navigation message data set, currently set to 3 hours [7]. A navigation message data set may be superseded before the expiration of these 3 hours by the broadcast of a new navigation message data set.

As previously stated, the Galileo OS Minimum Performance Levels are expected to be met only if the navigation solution is computed by a receiver using 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 may not meet the Minimum Performance Level. Furthermore, given the way the DVS and SHS flags can be set (section 2.2.2), a navigation data set within the maximum possible 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 performed by users at their own risk.

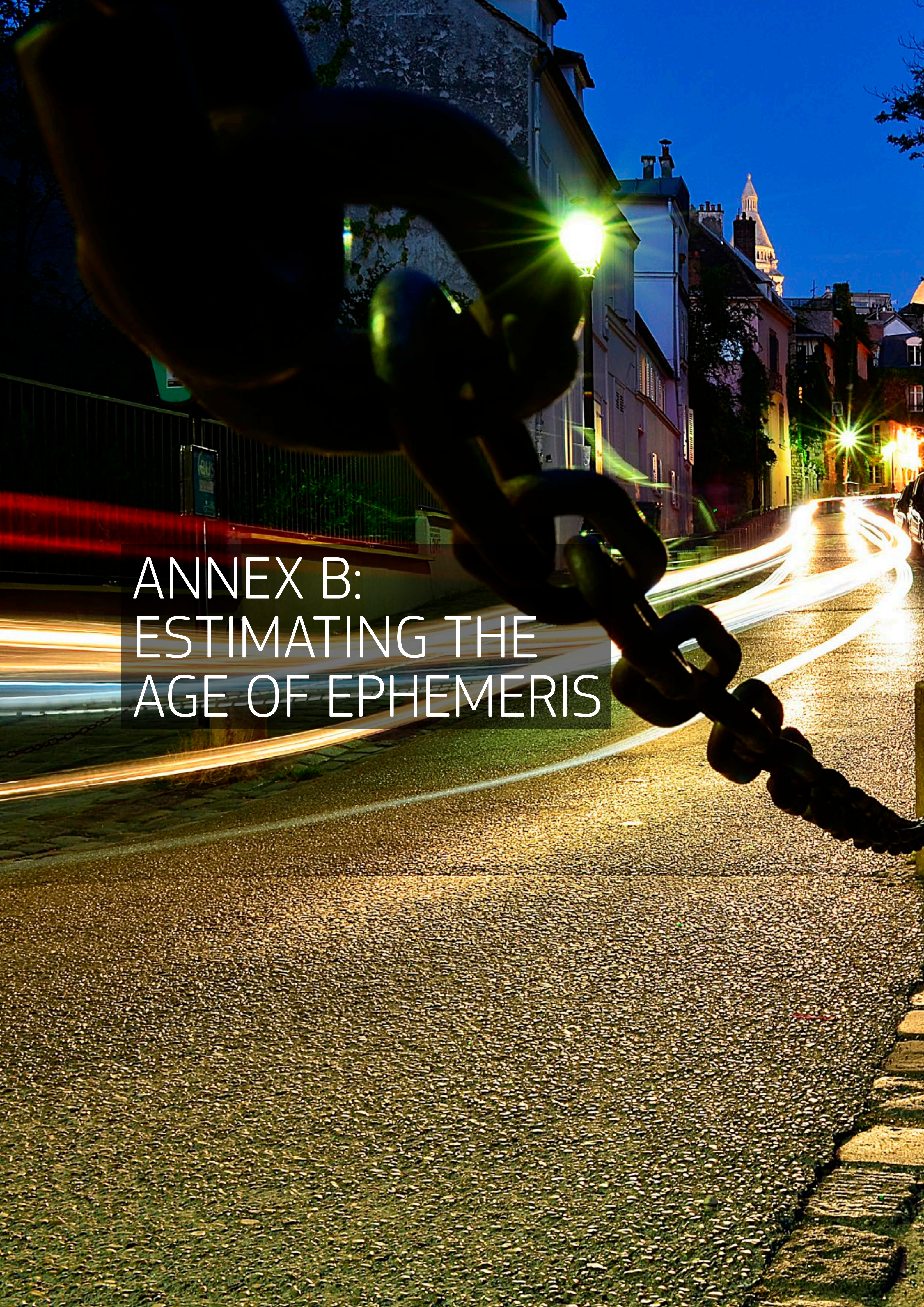
Concerning the GST-UTC conversion parameters, in the current system configuration they are updated daily (although this may change in a future configuration). With respect to the almanacs, their refresh rate is the same as for the navigation data

7....... *This time interval might be modified in the future. A procedure is described in Annex B of this document to estimate the Age of Ephemeris as prediction time from 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 possible broadcast period of a healthy navigation message data set.*

ANNEX A: REFERENCE DOCUMENTS

REFERENCE	TITLE	ISSUE
[1]	European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (OS SIS ICD).	Issue 1.2, European Union, 2015.
[2]	Ionospheric Correction Algorithm for Galileo Single Frequency Users.	Issue 1.1, European Union, 2015.

ANNEX B: ESTIMATING THE AGE OF EPHEMERIS



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 navigation data set is within a certain validity time VT it will have to evaluate the following inequality:

$$0 \leq t_k \leq VT$$

Note that, as explained in Annex A[1] (see Note to Table 58), tk 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 seconds, 604800 seconds must be subtracted from t_k. If t_k is less than -302400 seconds, 604800 seconds must be added to t_k.