PROGRAMME OF THE EUROPEAN UNION

NAVIGATION MADE IN EUROPE
GALILEO

I/NAV Navigation Message Improvements

Info Note

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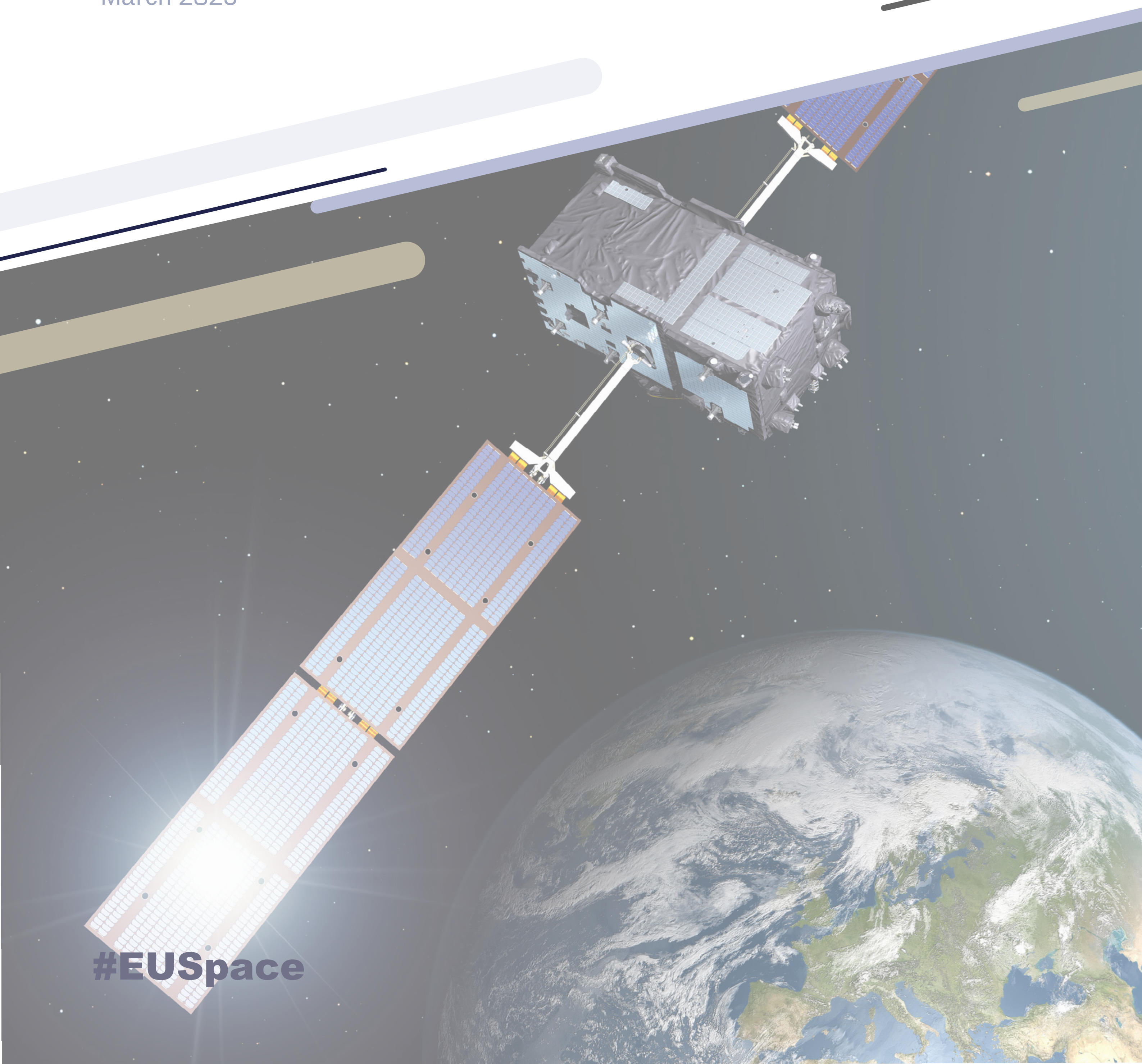

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1 ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
CED	Clock and Ephemeris Data
FEC	Forward Error Correction
FRE	Fitting Range Error
ICD	Interface Control Document
RedCED	Reduced Clock and Ephemeris Data
RS	Reed Solomon
SIS	Signal in Space
SSP	Secondary Synchronisation Pattern
TTD	Time to Data
TTFF	Time to First Fix
TTT	Time to Time

Table 1: Abbreviations

2 REFERENCE DOCUMENTS

Reference Documents		
Type	Title	Reference
RD 1	The European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document	OS SIS ICD v2.0
RD 2	Improving the Performance of Galileo E1-OS by Optimizing the I/NAV Navigation Message	Available on GSC web site
RD 3	Galileo Open Service - Service Definition Document	OS SDD v1.2

Table 2: Reference Documents

3 I/NAV IMPROVEMENT

3.1 Introduction to the I/NAV improvements

With the objective to improve the performance of the Galileo Open Service (OS), three new features have been introduced in the Galileo OS SIS ICD 2.0 published in January 2021 [RD 1]:

- Reduced Clock and Ephemeris Data (RedCED)
- Reed-Solomon Outer Forward Error Correction (RS FEC2) encoding of the Clock and Ephemeris Data (CED)
- Secondary Synchronisation Patterns (SSP)

These features, collectively referred to as "I/NAV improvements", are available free of charge for all users of the Galileo Open Service (OS). Their implementation in the Galileo constellation started in August 2022 and will take place until mid-2023[1]. The I/NAV improvements are openly accessible through the I/NAV message[2] carried by the E1-B signal.

These new features, while ensuring full backward compatibility with existing Galileo receivers, further improve the robustness and the time required for Galileo navigation data demodulation. In challenging environments, they enhance the Galileo OS capability to solve the user clock uncertainty.

The RedCED and the RS FEC2 contribute in different ways to improve the time to receive Clock and Ephemeris Data (Time To CED). This metric is especially relevant when a GNSS receiver operates in unassisted mode. Moreover, an improvement in the time to CED translates directly into an enhancement on the overall Time to First Fix (TTFF[3]).

The Secondary Synchronisation Patterns instead target applications working in GNSS assisted mode, i.e. where navigation data is received from non-GNSS channels and the user's knowledge of the Galileo System Time is within ±3 sec. In this situation, it is key to rapidly solve the user clock uncertainty and increase the robustness of the time synchronisation. To this end, users can now make use of the SSP.

These I/NAV improvements features are described here below.

3.2 I/NAV improvement new features

3.2.1 Reduced CED

The full precision Galileo Clock and Ephemeris Data (CED) consist of 428 bits, distributed over four I/NAV words (I/NAV-1, -2, -3, 4), that all need to be correctly demodulated in order to reconstruct the information. The newly introduced Reduced Clock and Ephemeris data (RedCED) compresses the CED parameters into 122 bits that can be transmitted in a single I/NAV word (I/NAV-16). Based on redCED the reception of the single I/NAV-16 word is sufficient. RedCED allows for a fast, initial position, albeit with lower than nominal accuracy, by only decoding one single I/NAV word and while waiting to receive the four I/NAV words carrying the full-precision CED. In this way, a TTFF (95% of the time) of up to 16 seconds can be achieved with a GNSS receiver using only Galileo signals, in open sky conditions.

This improvement of the TTFF by using the RedCED implies a lower than nominal ranging accuracy (see Section 3.3.2). Therefore, the use of RedCED must be limited to the acquisition of the initial fix and in any case not longer than their validity period of 600s (see [RD 1]). The use of RedCED beyond their validity period implies a rapid degradation of the resulting accuracy. On this regard, it is recalled that the full accuracy with standard CED parameters can be reached with a TTFF of 22 seconds when making use of the RS2 (see 3.2.2).

It is to be noted that the Galileo satellites transmit Reduced CED only if the E5b and E1-B Data Validity Status and Signal Health Status (SHS) flags are set to "0", and if SISA(E1,E5b)≠NAPA (i.e. the SIS

[1] At the time of the publication, there are already 13 updated satellites.

[2] The I/NAV message is the navigation message broadcast on Galileo E5b-I and E1-B signal components [RD 1].

[3] The time it takes from the start of a receiver to the availability of its position.

status of the subject satellite is “Healthy”). Therefore the reception of a RedCED word type (I/NAV-16) implies directly that the corresponding satellite is flagged "Healthy" (i.e. SHS=0) without the need to demodulate SHS, DVS and SISA.

3.2.2 Reed Solomon Outer Forward Error Correction

I/NAV improvement also includes the broadcast of additional Reed Solomon Clock and Ephemeris Data (RS-CED) encoded by the RS FEC2. The set of 4 RS-CED I/NAV words (I/NAV-17, -18, -19, -20) provide redundant information on top of the CED I/NAV words (I/NAV-1, -2, -3, -4). The full precision CED data can now be re-constructed after the successful demodulation of any four different I/NAV words out of the following eight I/NAV words:

- CED I/NAV words (I/NAV-1, -2, -3, -4)
- RS-CED I/NAV word (I/NAV-17, -18, -19, -20).

The introduction of RS-CED words provides the capability to correct residual errors as well as to recover erased information.

This I/NAV improvement enables increased demodulation robustness and therefore enhances the sensitivity in harsh environments but also improves the overall Time to retrieve Clock and Ephemeris Data (time to CED) in nominal conditions thanks to the broadcast of additional, redundant information.

3.2.3 Secondary Synchronisation Pattern

This new information provided within the I/NAV message allows reconstruction of the Galileo system time as long as a coarse synchronisation (+/-3 seconds) is also already available. User receivers can perform the correlation with the SSP sequence at symbol level without the need to demodulate the navigation message, thereby enabling time synchronisation even with weak signals.

3.2.4 Backward Compatibility

These new features are included in the I/NAV navigation message of the satellites that have been upgraded, and full backward compatibility is guaranteed, i.e. there is no impact on receivers developed following previous issues of the OS SIS ICD (Issues 1.4 or earlier) that are already on the market. The Galileo OS user receivers have always been expected to be able to recognize page types, to identify their content, and to react in a well-controlled manner to unknown page types as well as to variations in the order of received pages (refer to OS SIS ICD Issue 2.0 [RD 1], Section 4.1.2).

Consequently, when the Galileo satellites start transmitting these new I/NAV messages, receiver manufacturers can decide whether or not to exploit them.

3.3 I/NAV performance improvements

The Galileo Programme is committed to continuous improvement of the Galileo Open Service. With I/NAV improvements Galileo enables for the users the possibility to considerably boost their performance in terms of robustness and Time To First Fix (TTFF). In this context, ‘robustness’ includes the capability of the navigation message to enable a fast reconstruction of the Galileo System Time (GST). Additionally, as the time to receive clock corrections and ephemeris data is a major contribution to the Time To First Fix in many conditions, a reduction of this time supports in general all applications that require reception of this data from navigation signals.

As explained above, the Reduced CED and the RS FEC2 enable receivers to reduce the time to first fix by reducing the time to CED.

3.3.1 General time to first fix performance

The improvement in terms of time to (full and reduced) CED as expected for a user implementing RedCED and RS FEC2 is provided in the figures hereafter for some example cases, i.e. a user in an open sky environment, a vehicular user (50 km/h) in an urban environment and a pedestrian user (5 km/h) in an urban environment[4]. For all cases the Time-To-CED expected with the legacy I/NAV data is provided as a means of comparison. Note that in the figures the time axes represent the 95% success rate.

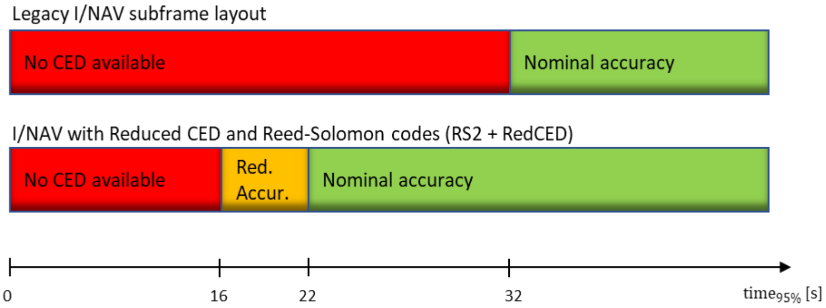


Figure 1: Time to CED (95%) for a user with perfect channel conditions in an open sky environment (from design phase)

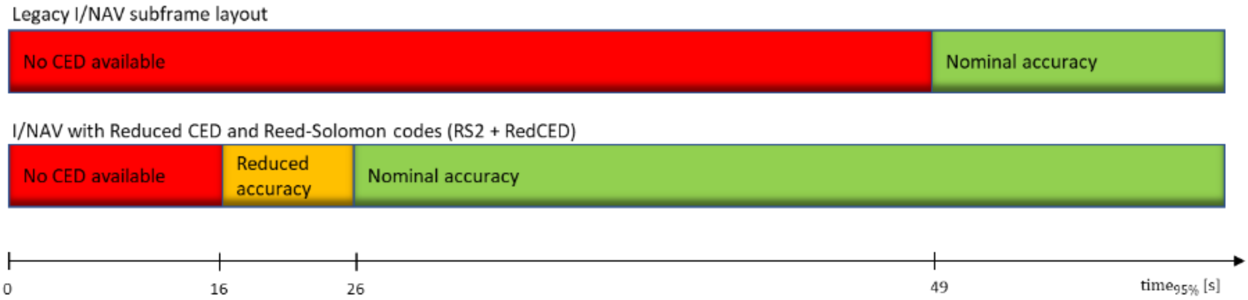


Figure 2: Time to CED (95%) for a vehicular user (50 km/h) in an urban environment (from design phase)

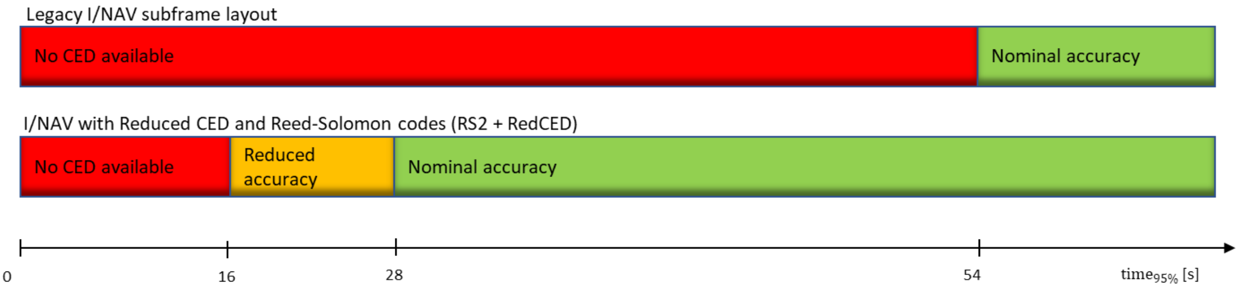


Figure 3: Time to CED (95%) for a pedestrian user (5 km/h) in an urban environment (from design phase)

These results show clearly that the provision of the Reduced CED is of great advantage for the computation of the first position fix. The RedCED word repeated twice every 30 seconds gives the users a much higher chance to receive CED during good channel state conditions, even if these just hold for short time intervals. It is also important to underline the great performance gain enabled by the Reed Solomon encoded CED pages, through which the time to achieve nominal accuracy is significantly reduced.

[4] These results are obtained through simulations including proper channel modelling. All details and relevant assumptions are provided in [RD 2].

During a validation campaign carried out using the first two satellites that were updated with the I/NAV improvements, different performance parameters have been measured. Some of the results are provided in the next sections, for three key figures of merit.

3.3.2 RedCED Ranging Error performance

The $SISE_{RedCED}$ is the Signal In Space Ranging Error[5] (SISE) when exploiting the RedCED parameter as broadcast by the Galileo system. This important performance has been monitored during the validation campaign. As depicted in Figure 4, the results show a typical $SISE_{RedCED}$ at Worst User Location (WUL) of 4.5m (95%).

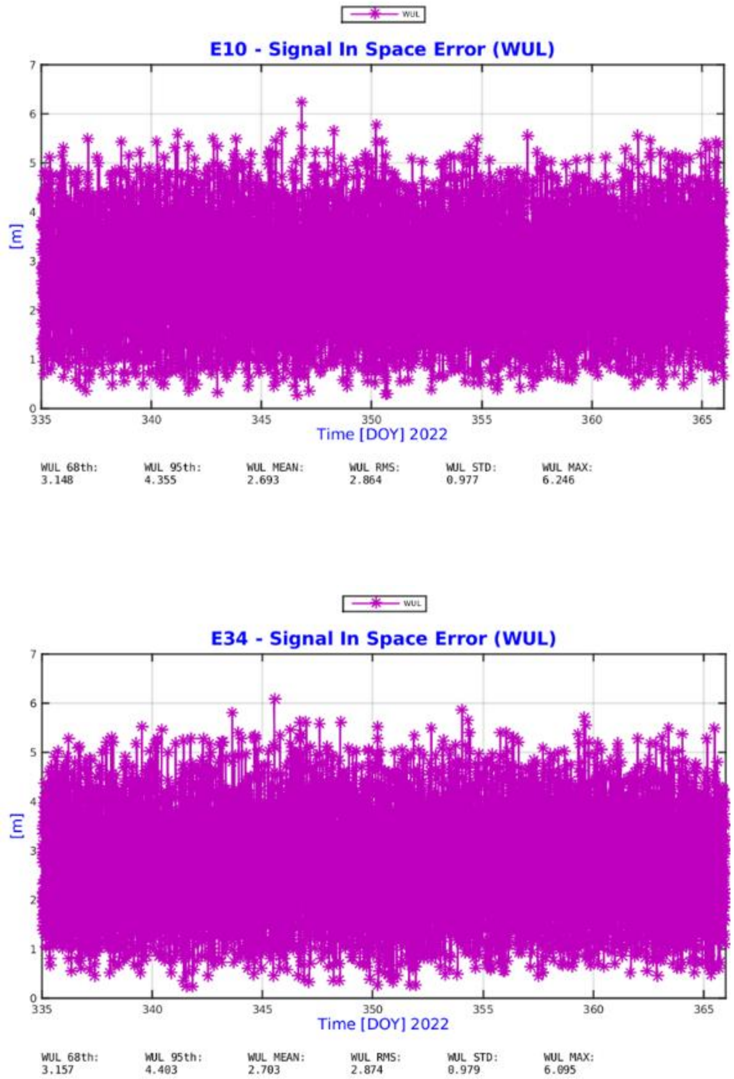


Figure 4: $SISE_{RedCED}$ performance measured during the validation campaign for two satellites

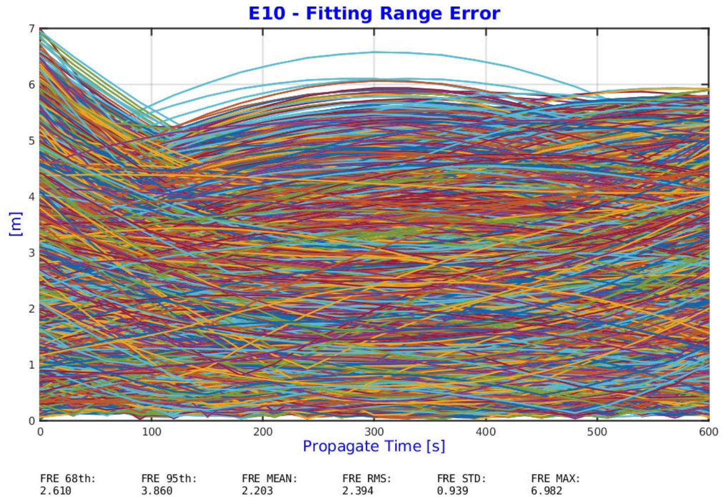
The SISE RedCED is the combination of the following two error sources:

- Signal in Space Error (SISE), which comprises the orbit and clock error when applying the Galileo precise Clock and Ephemeris Data (I/NAV-1, -2, -3, -4). The typical SISE error as measured from the constellation in operation is in the order of 0.25 m (95%, Worst User Location)

[5] The Signal In Space Ranging Error is defined in OS SDD [RD 3].

- Fitting Range Error (FRE), which refers to the additional error when exploiting the Galileo RedCED parameters. The FRE is the consequence of the compression of orbit and clock information from 428 bits (I/NAV-1, -2, -3, -4) to 122 bits of the RedCED word I/NAV-16.This parameter is defined as the sum of absolute value of the clock minus radial full-RedCED error and the absolute value of the tangential satellite position full-RedCED error.

Figure 5 show the Fitting Range Error as obtained from the satellites broadcasting I/NAV improvements. The data provided in a single RedCED word has a validity of 600 seconds, starting from the time of broadcast. The figures evaluate the Fitting Range Error of all RedCED words broadcast over the period of a full month (December 2023) and over the validity period of 600 seconds.



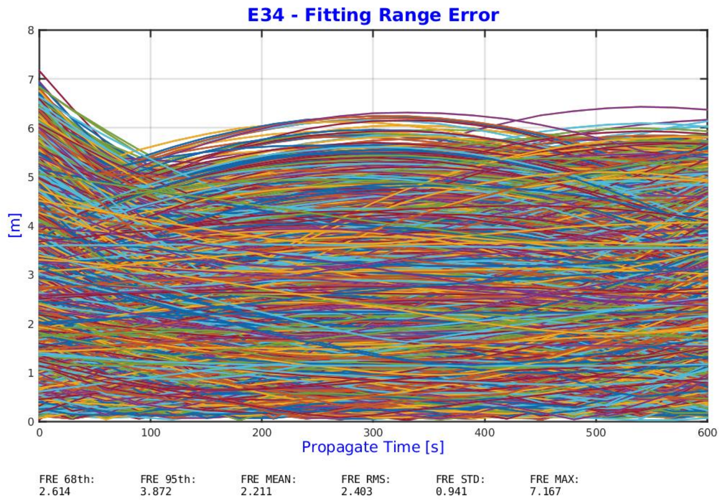


Figure 5: GSAT0224 and GSAT0223 Fitting Range Error during December 2022

3.3.3 Reed Solomon Clock and Ephemeris Data performance

Additional improvements are observed when using Reed Solomon encoded Clock and Ephemeris Data (RS-CED) that are provided in I/NAV-17, -18, -19, -20. The RS-CED data provides additional redundant CED information that allows to correct for lost or corrupted data.

The added value of the provision of RS-CED in addition to CED becomes evident when comparing the two cases in Table 3 that identify the data required to be demodulated by the user in order to achieve full Galileo CED accuracy:

	User without I/NAV improvement	User with I/NAV improvement
I/NAV words needed to reconstruct full precision CED	Correct demodulation of the following 4 I/NAV words: I/NAV-1, -2, -3 and -4.	Correct demodulation of 4 different I/NAV words out of a set of 8 words: I/NAV-1, -2, -3, -17, -18, -19, -20.
Lost or incorrect demodulation of a single word	Correct demodulation of the missing I/NAV word type needed at next possibility.	Correct demodulation of any other word

Table 3: RS-CED use cases

For instance, the Time To Data (TTD) refers to the time required to demodulate navigation message content from a single navigation signal. This parameter can be measured in two different ways, depending on which CED is being demodulated. The following performance was obtained during the testing campaign:

- TTD for coarse accuracy refers to the time to demodulate the RedCED parameters. The typical TTD for coarse accuracy exploiting I/NAV improvements is at the level of 16s (95%) [RD 2] in open sky environment;
- TTD for full accuracy refers to the time to demodulate data out of the navigation message that provides the full accuracy (i.e. full CED and/or RS-CED). The typical TTD for full accuracy exploiting I/NAV improvement (i.e. including RS-CED) is at the level of 22s (95%) [RD 2] in open sky environment (see Figure 6).

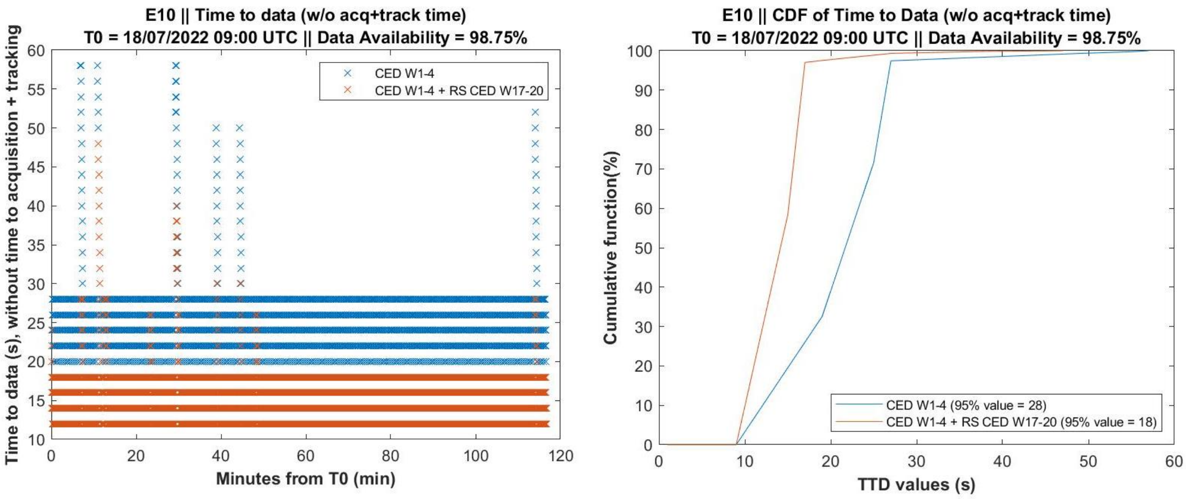


Figure 6: TTD performance measured during the validation campaign

3.3.4 Secondary Synchronisation Pattern performance

The Secondary Synchronisation Pattern enables a significant improvement of the receivers' time-to-synchronisation with the Galileo time, reducing it to 3 seconds, on the average[6].

The Time To Time (TTT) refers to the time required to retrieve the Galileo System Time (GST) information from the navigation message of a single Galileo navigation signal. The following performance was obtained during the validation campaign:

[6] 4 seconds in the worst case and 3.9 seconds 95% of time.

- TTT for time ambiguity resolution refers to the exploitation of SSP for time provision, provided that the receiver is already coarsely synchronised with GST within ±3s. The typical TTT for time ambiguity resolution exploiting I/NAV improvement (SSP) is at the level of 6s (95%) in open sky environment;
- TTT for absolute time refers to demodulation of absolute GST from navigation signal. The typical TTT for absolute time from legacy I/NAV is at the level of 13s (95%) in open sky environment.

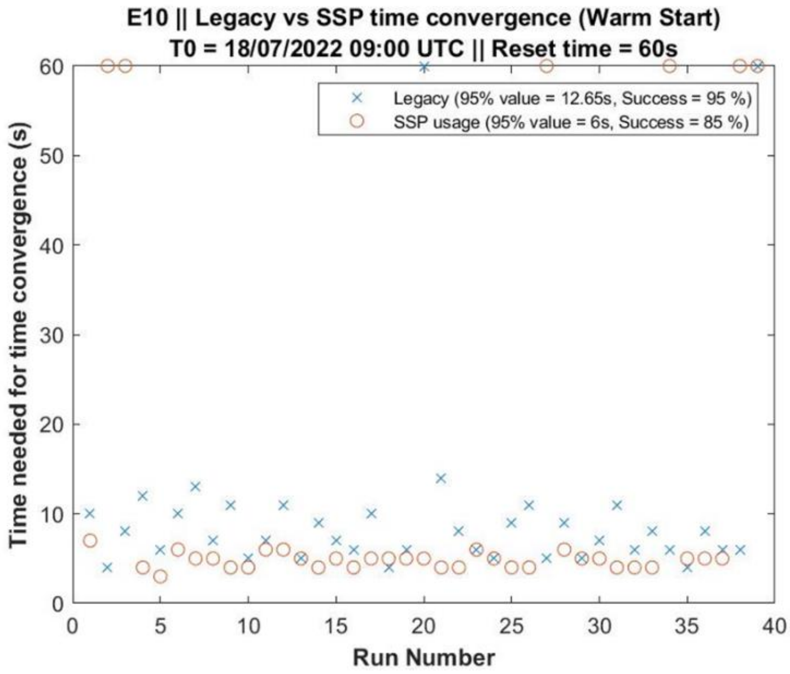


Figure 7: TTT performance measured during the test campaign

Further relevant information, including elements on possible implementation strategies, can be found in [RD 2].

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