engineering proceedings

MDPI

Proceeding Paper

Galileo Receiver Performance Analysis with New I/NAV Improvements Live Data †

Rui D. Nunes [1,*], Mahamoudou Ouedraogo [2], Susanne Schlötzer [2], Nityaporn Sirikan [3] and Stefan Wallner [3]

[1] Deimos Engenharia, 1070-061 Lisbon, Portugal
[2] Airbus Defense and Space GmbH, 81663 Munich, Germany; mahamoudou.ouedraogo@airbus.com (M.O.); susanne.schloetzer@airbus.com (S.S.)
[3] European Space Agency, 2200 AG Noordwijk, The Netherlands; nityaporn.sirikan@esa.int (N.S.); stefan.wallner@esa.int (S.W.)
* Correspondence: rui.nunes@deimos.com.pt
† Presented at the European Navigation Conference 2023, Noordwijk, The Netherlands, 31 May–2 June 2023.

Abstract: This work presents the results showing the improvement of the performance of a Galileo receiver processing the new I/NAV words 16–20 and SSP in comparison to the performance using the previous legacy I/NAV configuration. The results were obtained by replaying GNSS signals recorded in Urban and Open Sky mobile environments when at least four satellites broadcasting the new words were visible. The results show an improvement of Time to First Fix values using RedCED (word 16) and FEC2 (words 17–20) in cold start conditions and a reduction in time needed to converge using SSP when coarse time (within 3 s error) is available.

Keywords: Galileo; E1 band; I/NAV improvements; secondary synchronization pattern; Reed–Solomon; reduced CED; Time to First Fix

check for updates

Citation: Nunes, R.D.; Ouedraogo, M.; Schlötzer, S.; Sirikan, N.; Wallner, S. Galileo Receiver Performance Analysis with New I/NAV Improvements Live Data. *Eng. Proc.* **2023**, *54*, 43. https://doi.org/10.3390/ENC2023-15422

Academic Editors: Tom Willems and Okko Bleeker

Published: 29 October 2023

1. Introduction

In order to compute its time and position, a Galileo receiver needs to decode the Clock and Ephemeris Data (CED) information of the satellites present in the message obtained via the received signals from space. The speed of the retrieval of CED from four different satellites will have a direct impact on the Time to First Fix (TTFF). The legacy I/NAV message in Open Service E1B and E5B [1] contains the CED information on words 1–4, and all need to be decoded in the same Issue of Data (IoD) to provide the necessary information of the satellite. These words are distributed in the subframes according to Table 1, meaning that, in perfect conditions (with no data loss), the minimum time needed to retrieve CED is 14 s. With four satellite channels tracked in parallel, the TTFF computation is straightforward, although, in environments with less visibility and/or degraded reception, the computation of the CED of four different satellites will take significantly longer.

The inclusion of Reduced CED (hereafter RedCED) word 16 and Outer Forward Error Correction (FEC2) based on Reed–Solomon (hereafter RS) words 17–20 [2,3] was proposed in order to improve the conditions of CED information retrieval. The RedCED word 16 contains the information of legacy words 1–4 compressed in a single word with reduced bits (and, therefore, reduced accuracy), while RS words 17–20 complement words 1–4 with information protected via the FEC2 RS algorithm that will complement words 1–4, as shown in Table 1. By computing the new words, the data decoding and TTFF value are greatly improved in comparison to the legacy configuration.

The introduction of the Secondary Synchronization Pattern (hereafter SSP) [2] is intended to improve the time needed for time convergence when a coarse estimate is available (within +/− 3 s), as it will resolve the ambiguity when the receiver retrieves SSP bits pattern every 2 s among three possible patterns. The SSP information is present on the raw navigation data bits with no need to decode further data.

Table 1. I/NAV message subframe layout (Blue = Legacy CED, Green = RS CED, Orange = Reduced CED).

T_0 (s)	Legacy E1B I/NAV	Improved E1B I/NAV
1	W02	W02
3	W04	W04
5	W06	W06
7	W07/W09	W07/W09
9	W08/W10	W08/W10
11	W00	W17/W19
13	W00	W18/W20
15	W00	W16
17	W00	W00
19	W00	W00
21	W01	W01
23	W03	W03
25	W05	W05
27	W00	W00
29	W00	W16

In this paper, the improvements of RedCED, RS, and SSP are shown by comparing the performance of the configuration using the new words with the configuration using the legacy I/NAV message with live signal data. For further reading on Reduced CED and FEC2 RS CED, refer to [4,5].

2. Materials and Methods

The first step is the collection of GNSS signals via a Radio Frequency recorder in a mobile testbed vehicle in both Urban and Open Sky environments (Figure 1). The time windows were chosen in order to have a minimum of 4 visible satellites with the new I/NAV Improvement features. The data collection resulted in a total of 2 h of Urban environment data collection and 4 h of Open Sky environment with 4 to 6 satellites visible in the sky broadcasting the new I/NAV improvements. It is important to note that since the I/NAV update in the constellation is still being deployed, the performance characterization is based on live data recorded from a reduced subset of satellites. The recorded GNSS signals were replayed in the ESA Navigation Laboratory connected to a Septentrio Test User Receiver (TUR-N) able to process the new I/NAV Improvement features. All tests were performed in Single Frequency (SF) mode using E1B signal. In order to properly compute the improvement of the new features with the same satellite constellation geometry and visibility, all tests were conducted using only the satellites broadcasting the new I/NAV features.

Figure 1. Vehicle used for mobile data collection.

For RedCED and RS performance tests, the receiver is reset via an automatic setup in cold start in order to evaluate individual satellite data demodulation time (excluding acquisition and tracking time) through a statistically significant number of points. Figure 2 presents both Data Demodulation and TTFF time, but the results in Section 3 focus only on Data Demodulation improvement using the new I/NAV features, as the overall TTFF is also impacted by the acquisition and tracking time.

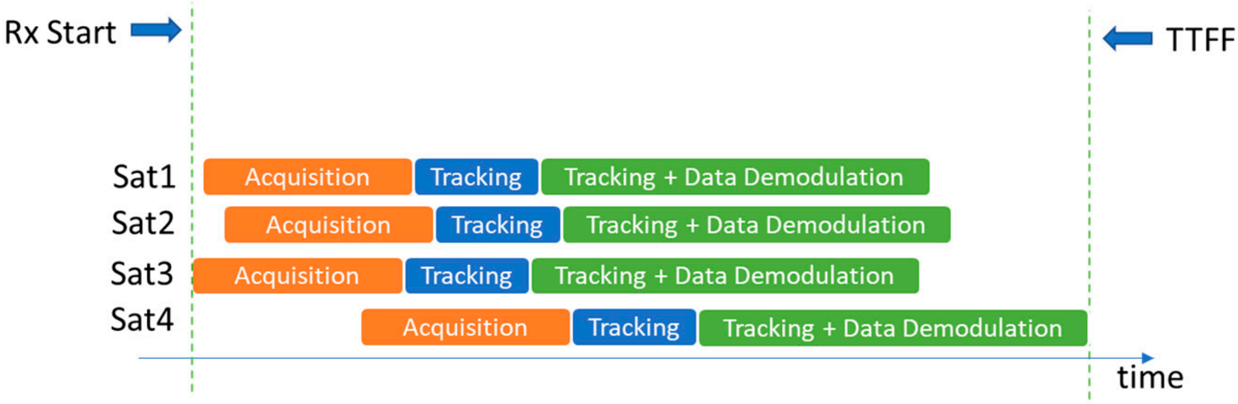

Figure 2. Data Demodulation and TTFF visual scheme.

For SSP, the receiver is reset via an automatic setup in warm start where a coarse time estimate is provided to the receiver after each reset (for the legacy time retrieval, the provided coarse time estimate has no effect). As these upgraded satellites broadcast both legacy and new words, it is possible for the receiver to choose which words to process. The RS, RedCED, and SSP tests' reset starting times are chosen randomly in order to evenly distribute the entry points of the I/NAV subframe.

3. Results

This section covers the results of the time needed for satellite data demodulation using the new words RS (words 17–20) and RedCED (word 16) in the cold start and the time needed for time convergence using SSP in the warm start.

3.1. Reed–Solomon and Reduced CED Results

The results in this section present the statistical value of Data Demodulation by computing the needed time for each satellite to retrieve the necessary CED words. The values of Time to Data (TTD) were grouped per scenario case (Urban or Open Sky) for the first four satellites retrieved per reset point for all reset points within each scenario. For each satellite, the legacy configuration computes CED 1–4, while the RS configuration computes any four different words from CED 1–4 + CED 17–20, and the RedCED + RS configuration computes either RedCED W16 or the same words as RS configuration. In order to fully benefit from RS CED, the receiver is not waiting for W05, which does contain Signal-In-Space (SIS) health status information, Broadcast Group Delay (BGD), Galileo System Time (GST), and Ionospheric correction data:

- Confirmation of healthy SIS status can be derived from the presence of W16. In case the SIS is flagged as unhealthy or marginal, W16 is not broadcast via the Galileo satellite and is replaced with W05.
- BGD information is generally stable over a long time and can be reused from information retrieved earlier and stored in the receiver.
- Galileo System Time can be recovered from SSP, assuming the receiver has a residual time uncertainty of +/− 3 s or can be retrieved from W05 decoded from any other satellite.
- Ionospheric correction data can be retrieved from W05 decoded from any other satellite or can be omitted at the cost of higher ranging error.

Figure 3a shows the results in the Open Sky environment. Looking at the 95 percentile of the data demodulation in Figure 3a, we see an improvement of 10 s (33.3%) using RS and 16 s (53.3%) using RS + RedCED. The Open Sky results are deterministic since, in ideal conditions, the retrieval of the CED words is a function of the I/NAV sub-frame layout. Therefore, the obtained results are useful to confirm the obtained theoretical values.

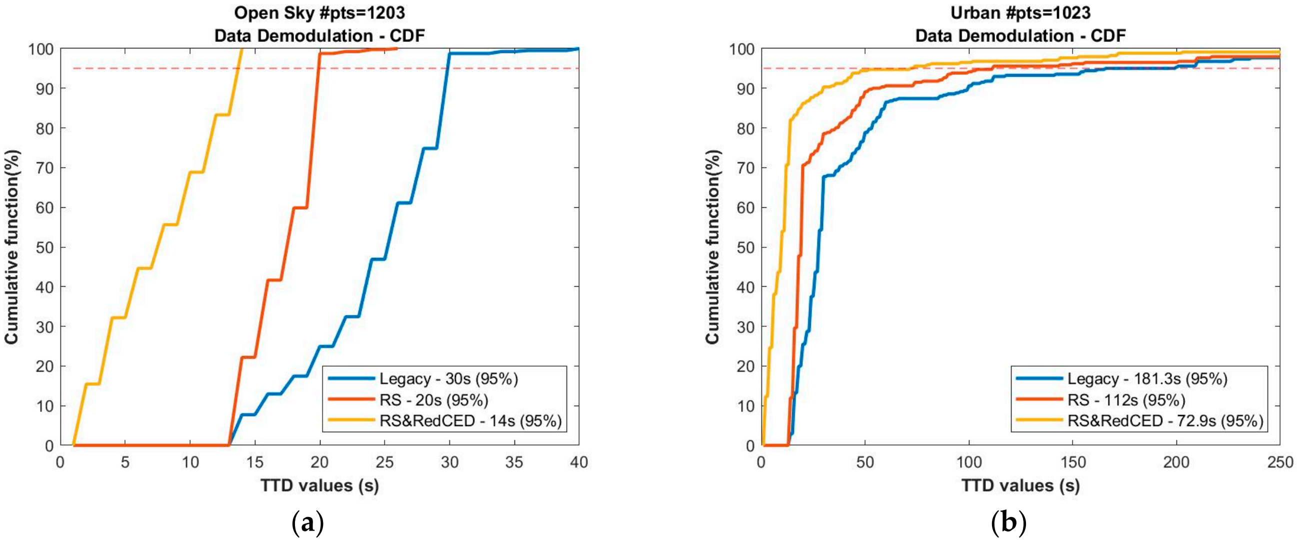

Figure 3. Comparison of legacy I/NAV to RS (I/NAV 17–20) and RedCED (I/NAV 16) Data Demodulation: (**a**) Open Sky CDF of Data Demodulation and (**b**) Urban CDF of Data Demodulation.

Figure 3b shows the results in an Urban environment. Compared to the Open Sky results, the increase in the data demodulation time in the Urban case is caused by the loss of words due to the loss of satellite visibility. Looking at the 95 percentile of the data demodulation in Figure 3b, we see an improvement of 69.3 s (38.2%) using RS and 108.4 (59.8%) using RS + RedCED.

As a complement to the displayed results, we have included the maximum and average data demodulation values for both Open Sky and Urban scenarios. It is important to note that the results for the Urban scenario are highly dependent on the specific dataset used and should be considered illustrative examples:

- Open sky:
  - Legacy: max = 40 s, average = 24.5 s.
  - RS: max = 26 s, average = 17.5 s.
  - RS + RCED: max = 14 s, average = 8 s.
- Urban
  - Legacy: max = 448 s, average = 48.1 s.
  - RS: max = 404 s, average = 35.5 s.
  - RS + RCED: max = 400 s, average = 18.9 s.

3.2. Secondary Synchronization Pattern Results

Figure 4a,b show the results in the Open Sky environment. Looking at the 95 percentile value of the time needed for time convergence in Figure 4a, we see an improvement of 5 s (35.7%) using SSP, while Figure 4b shows the histogram where the distribution of the values is represented.

Figure 4c,d show the results in an Urban environment. Looking at the 95 percentile value of the time needed to time convergence in Figure 4c, we see an improvement of 4.2 s (23.1%) using SSP, while Figure 4d shows the histogram where the distribution of the values is represented.

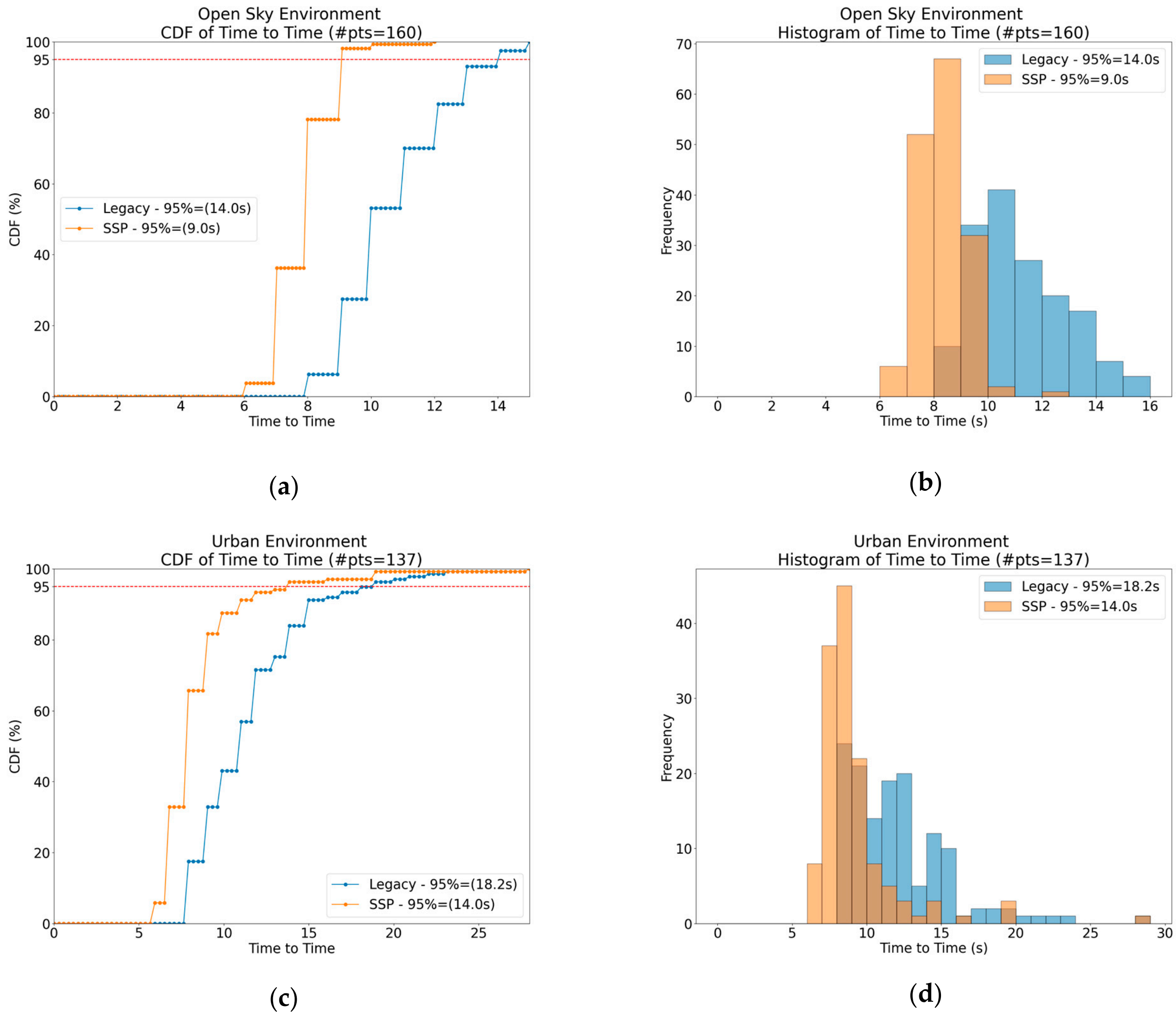

Figure 4. Comparison of legacy I/NAV to SSP time-to-time convergence: (**a**) Open Sky CDF, (**b**) Open Sky histogram, (**c**) Urban CDF, (**d**) Urban histogram.

4. Conclusions

Table 2 presents the summary of the results of RS and RedCED features in receiver cold start conditions. Overall, there is an improvement in data demodulation time from 33–38% using RS and 53–60% using RS + RedCED in Open Sky and Urban conditions, which results in an improvement in the TTFF value. The improvements are particularly important in Urban environments where the visibility is reduced and the signal is lost, resulting in receiver position reset and re-fix. Note that, as described previously, the number of satellites used was filtered in order to compare coherently the performance of the new features with the legacy features using the same broadcasting satellites. Therefore, particularly in urban conditions, the visibility was reduced to 4–6 simultaneous satellites, which has a big impact on CED computations, resulting in an increase in the absolute value of TTFF. Nonetheless, this exercise is very useful for retrieving the relative improvement when using the new features.

Comparing the obtained results with previously simulated data in [3], the values are in the expected range, confirming the simulated data with real data broadcast via the upgraded satellites.

Table 3 presents the summary of the results of time convergence using SSP when time is provided within 3 s error. The results vary from 23 to 36% in improvement in both Open Sky and Urban environments. The new SSP feature will result in faster re-synchronization with the Galileo System Time (GST) for the connected (or assisted) users.

Table 2. Results of 95 percentile Data Demodulation (DD) using RS and RedCED.

Test Case	DD: Legacy (s)	DD: RS (s)	DD: RS + RedCED (s)
Open Sky	30.0	20.0 (−33.3%)	14.0 (−53.3%)
Urban	181.3	112.0 (−38.2%)	72.9 (−59.8%)

Table 3. Time convergence results using SSP with coarse time provided.

Test Case	Legacy (s)	SSP (s)
Open Sky	14.0	9.0 (−35.7%)
Urban	18.2	14.0 (−23.1%)

Additionally, the presented results utilize a single-frequency signal, GAL E1B, which currently broadcasts the new features. However, please note that E5B is not currently broadcasting the new I/NAV features. If you use dual-frequency with E5B, it will enhance the performance of the legacy I/NAV system. This, in turn, will result in a reduced relative improvement when using RS and RCED.

Author Contributions: Conceptualization, R.D.N.; methodology, R.D.N.; software, R.D.N.; validation, R.D.N. and S.W.; formal analysis, R.D.N.; investigation, R.D.N.; resources, R.D.N.; data curation, R.D.N.; writing—original draft preparation, R.D.N.; writing—review and editing, S.W., N.S., S.S. and M.O.; visualization, R.D.N.; supervision, S.W., M.O. and N.S.; project administration, S.W., M.O. and N.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data cannot be made publicly accessible as they are subject to internal restrictions imposed by a dedicated test campaign.

Acknowledgments: The material and laboratory activities were supported by the ESA Navigation Laboratory. This work was also possible due to the support of the Galileo Receiver Team in Estec: Xurxo Otero, Luciano Musumeci, Matteo Fè, and César Vázquez.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (OS SIS ICD), Issue 2.0, January 2021. Available online: https://www.gsc-europa.eu/sites/default/files/sites/all/files/Galileo_OS_SIS_ICD_v2.0.pdf (accessed on 28 November 2023).
2. Paonni, M.; Anghileri, M.; Burger, T.; Ries, L.; Schlötzer, S.; Schotsch, B.E.; Ouedraogo, M.; Damy, S.; Chatre, E.; Jeannot, M.; et al. Improving the Performance of Galileo E1-OS by Optimizing the I/NAV Navigation Message. In Proceedings of the 32nd International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2019), Miami, FL, USA, 16–20 September 2019; pp. 1134–1146. [CrossRef]
3. Peres, T.; Jimenez, D.; Burger, T.; Schotsch, B.E.; Anghileri, M.; Ouedraogo, M. A Novel Approach for Real-World Performance Assessment of Galileo Navigation Message Evolution. In Proceedings of the 31st International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2018), Miami, FL, USA, 24–28 September 2018; pp. 4079–4093. [CrossRef]

4. Schotsch, B.E.; Anghileri, M.; Ouedraogo, M.; Burger, T. Joint Time-to-CED Reduction and Improvement of CED Robustness in the Galileo I/NAV Message. In Proceedings of the 30th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2017), Portland, OR, USA, 25–29 September 2017; pp. 1544–1558. [CrossRef]
5. Schlötzer, S.; Söllner, M.; Burger, T.; Ouedraogo, M.; Anghileri, M.; Bey, T. Reduced Clock and Ephemeris Data making use of equinoctial parameterization. In Proceedings of the Navitec 2018, ESA/ESTEC, Noordwijk, The Netherlands, 5–7 December 2018.