The Improvements seen from Galileo's Signal Message I/NAV change

Galileo G1 Project Office

Presentation to UN ICG-17, WG-S

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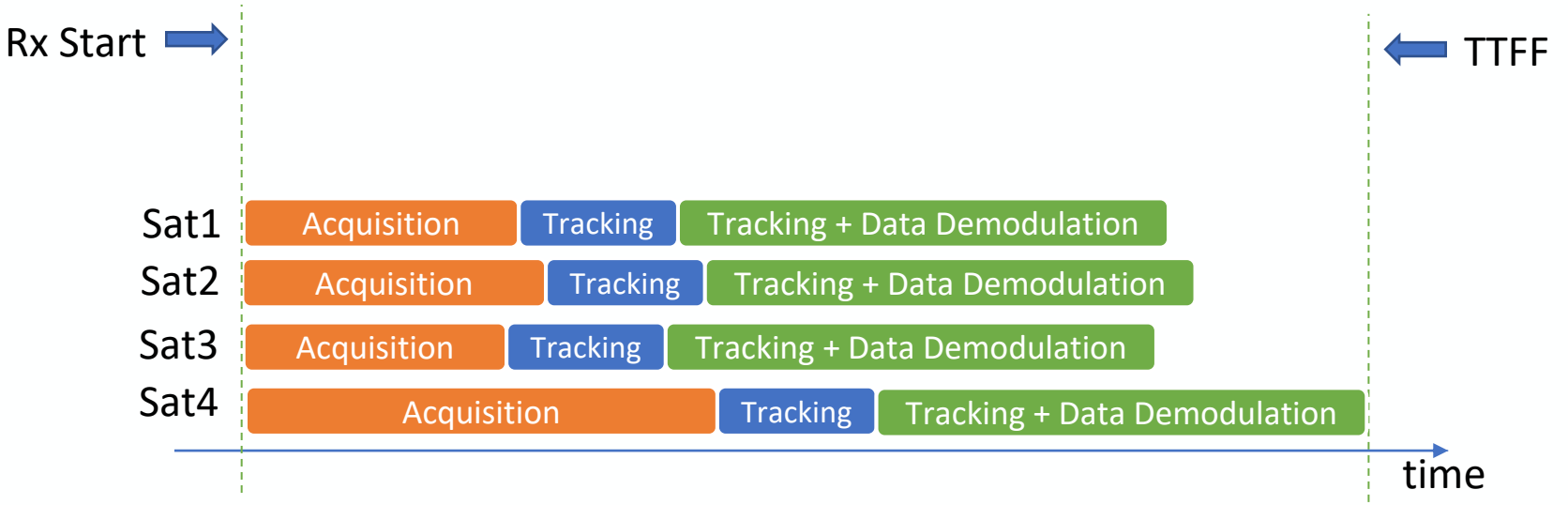
Introduction

- Time to First Fix (TTFF) in GNSS receivers is one of the main performance key performance parameters for positioning.
- The TTFF value is mainly impacted by Signal Acquisition and Data Demodulation time for each satellite.
- New features in E1B help improve the **Data Demodulation** step, with direct impact on TTFF.



I/NAV Improvement - Content

- I/NAV improvement has been designed to improve the data delivery of Galileo I/NAV along 3 axis
  - **Improved Time to First Fix** - fast retrieval of navigation data
  - **Improved data demodulation robustness** – demodulate nav data also in challenging environment
  - **Time ambiguity resolution** – for users with coarse time information (+/- 3 sec) to access Galileo system time without need to demodulate it from navigation message
- Implementation solution selected
  1. **Reduced Clock and Ephemeris** (redCED)
  2. **Reed Solomon** (RS)
  3. **Secondary Synchronisation Pattern** (SSP)

Public SIS-ICD contains I/NAV impr. spec since 01/2021

Deployment in Galileo Constellation is complete
20 satellites are broadcasting I/NAV improvement

It's there – use it!

Feature 1: Reduced Clock and Ephemeris Data

Basic Idea: Reduce the number of information required to generate a position fix (at cost of accuracy)

I/NAV Clock and Ephemeris Parameter

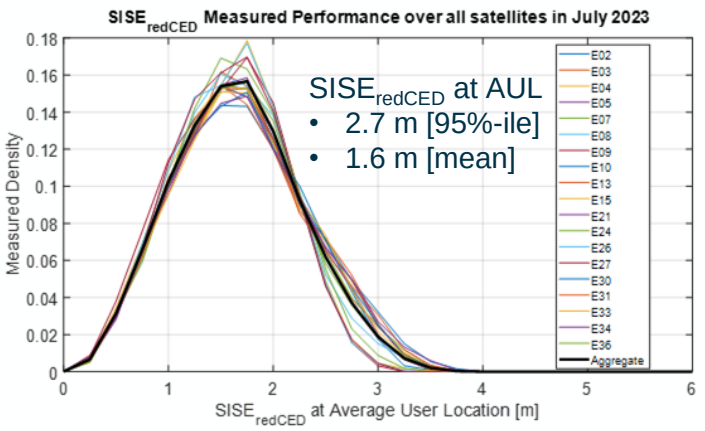
- are spread over 4 I/NAV words (I/NAV-1, -2, -3, -4)
- all 4 I/NAV words need to be received (with same IODnav) to establish a position fix

Parameter	Definition	Bits	Scale factor	Unit
M_0	Mean anomaly at reference time	32*	2^{-31}	semi-circle**
Δn	Mean motion difference from computed value	16*	2^{-43}	semi-circle/s**
e	Eccentricity	32	2^{-33}	dimensionless
$A^{1/2}$	Square root of the semi-major axis	32	2^{-19}	$m^{1/2}$
$OMEGA_0$	Longitude of ascending node of orbital plane at weekly epoch***	32*	2^{-31}	semi-circle**
i_0	Orbit inclination angle at reference time	32*	2^{-31}	semi-circle**
OMEGA	Argument of perigee	32*	2^{-31}	semi-circle**
OMEGADOT	Rate of change of right ascension	24*	2^{-43}	semi-circle/s**
IDOT	Rate of change of inclination angle	14*	2^{-43}	semi-circle/s**
C_{uc}	Amplitude of the cosine harmonic correction term to the argument of latitude	16*	2^{-29}	rad
C_{us}	Amplitude of the sine harmonic correction term to the argument of latitude	16*	2^{-29}	rad
C_{rc}	Amplitude of the cosine harmonic correction term to the orbit radius	16*	2^{-5}	m
C_{rs}	Amplitude of the sine harmonic correction term to the orbit radius	16*	2^{-5}	m
C_{ic}	Amplitude of the cosine harmonic correction term to the angle of inclination	16*	2^{-29}	rad
C_{is}	Amplitude of the sine harmonic correction term to the angle of inclination	16*	2^{-29}	rad
t_{0e}	Ephemeris reference time	14	60	s
Total ephemeris bits		**356**		

Table 7-2: Ephemeris parameters

Parameter	Definition	Bits	Scale factor	Unit
t_{0c}	Clock correction data reference Time of Week	14	60	s
a_{f0}	SV clock bias correction coefficient	31*	2^{-34}	s
a_{f1}	SV clock drift correction coefficient	21*	2^{-46}	s/s
a_{f2}	SV clock drift rate correction coefficient	6*	2^{-59}	s/s^2
Clock Correction Parameters		**72**		

Table 7-5: Clock correction parameters



428 bits

Reduced Clock and Ephemeris Parameter

- Idea: reduce number of CED parameters and bit allocation to squeeze all information into a single I/NAV word (**122 bits**)
- RedCED
  - are derived **on-board** from full CED
  - provide degraded accuracy compared to CED
- User exploitation:
  - First position fix with redCED

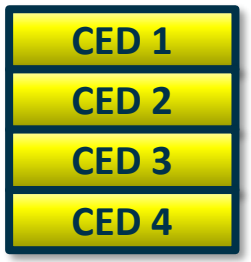
Parameter	Number of bits	Scale factor	Reference value	Unit
ΔA_{red}	5*	2^8	29600000	meter
e_{xred}	13*	2^{-22}	0	dimensionless
e_{yred}	13*	2^{-22}	0	dimensionless
Δi_{0red}	17*	2^{-22}	56/180	semi-circle**
Ω_{0red}	23*	2^{-22}	0	semi-circle**
λ_{0red}	23*	2^{-22}	0	semi-circle**
a_{f0red}	22*	2^{-26}	0	s
a_{f1red}	6*	2^{-35}	0	s/s
Total bits	**122**			

122 bits

Feature 2: Reed Solomon Coding of the Clock and Ephemeris Data

Introduction of Reed-Solomon Clock and Ephemeris Data (RS CED) to the I/NAV message (E1-B)

- RS coding provides
  - Correction of residual errors **AND** recovery of erased information
- 4 different RS CED word are generated **on-board** (obtained from CED), per sub-frame 2 RS CED words are broadcast
- Any set of four different error free received (RS) CED words recovers the CED
  - Examples:



CED recoverable:
all CED words available

CED *not* recoverable:
CED 4 is missing
doublets are not useful

CED recoverable:
CED 2 & 3 can be recovered by using **joker words** RS CED 1 & 2

CED *not* recoverable:
four *different* words are required

CED recoverable:
four *different* words are available

RS-CED is the “Joker” Word
(can replace any CED word)

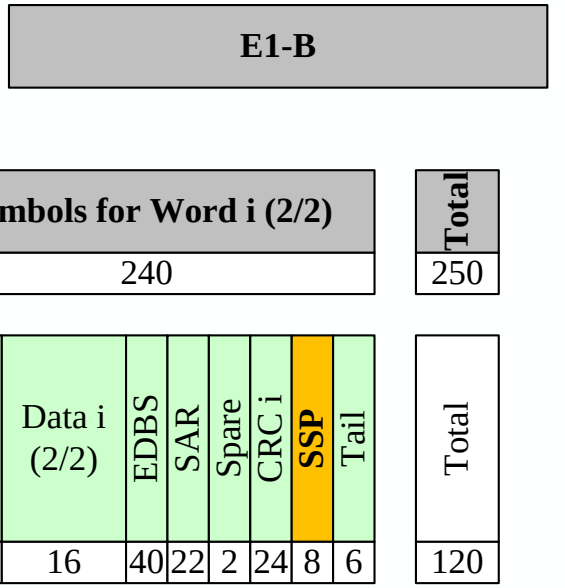
Feature 3: Secondary Synchronization Pattern

Introduction of Secondary Synchronization Pattern (SSP) into the I/NAV message (E1-B) supports reconstruction of the GST, without the need to demodulate the navigation message

	SSP1	SSP2	SSP3
Plain SSP configurations	00000100	00101011	00101111

- SSP replaces spare bits on E1-B
- Required level of coarse synchronisation
- Ambiguous Time Of Week (TOW) information can be retrieved
  - SSP1 detected → TOW modulo 6s = 1s
  - SSP2 detected → TOW modulo 6s = 3s
  - SSP3 detected → TOW modulo 6s = 5s

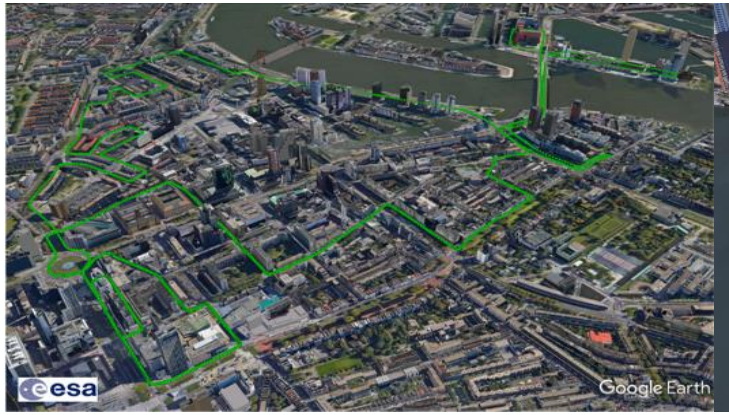
Enables fast GST recovery (modulo 6 seconds) already at symbol level



Test Campaign

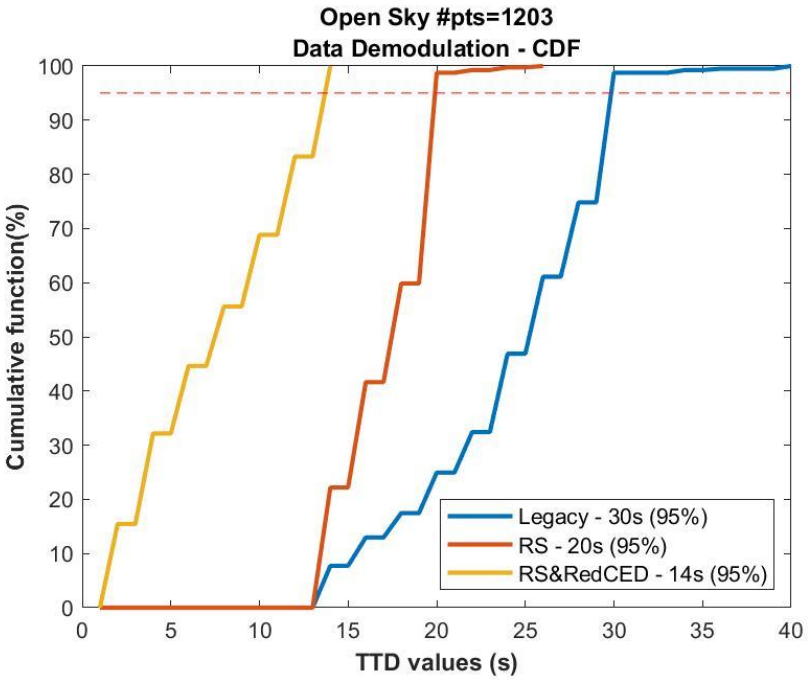
Rural (Nieuw Vennep)

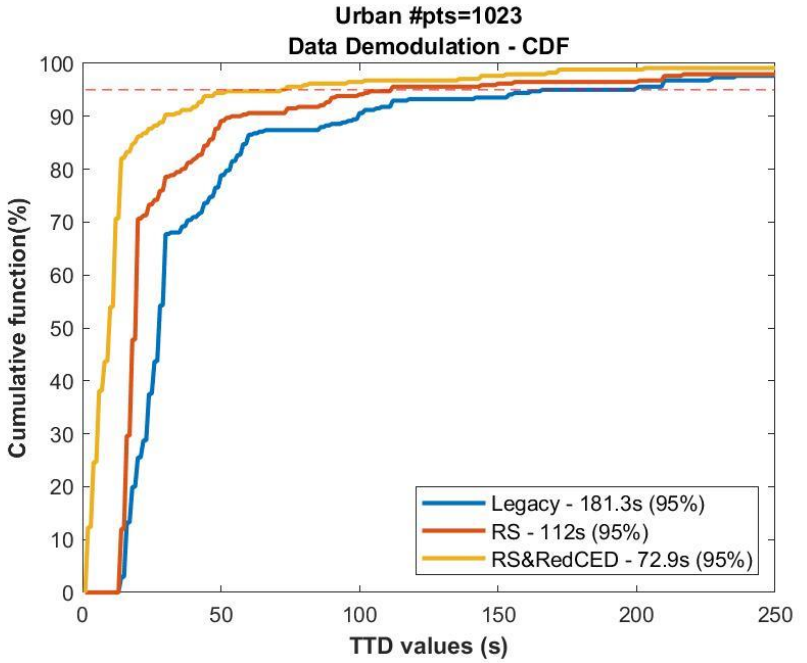
Urban (Rotterdam)



Campaign Results – RS and RedCED Performance

- KPI measured: Data demodulation time





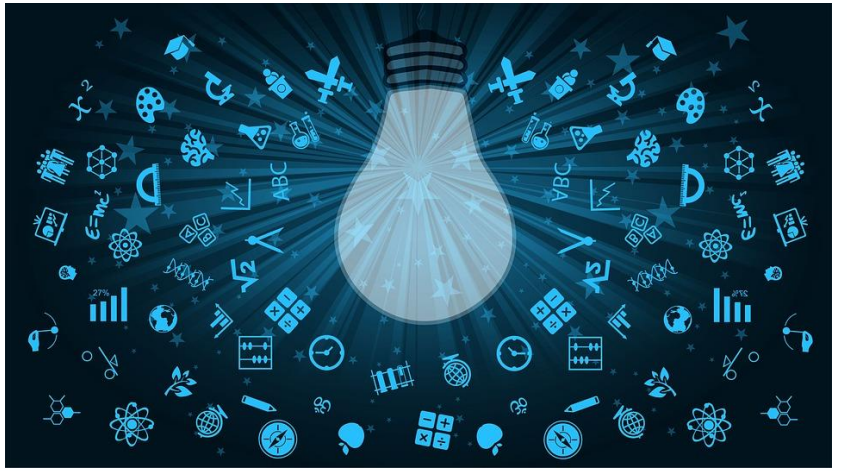
2x faster with I/NAV impr.

Important Note

In order to fully benefit from RS-CED, specific attention needs to be paid to W05 handling:

Do not wait to demodulate W05, but

- Derive healthy SIS status from the presence of W16. W16 is only broadcast when SIS is Healthy
- BGD: retrieve from previously stored data – information is stable over long time
- Galileo System Time: recover from SSP or from W05 decoded from any other satellite
- Ionospheric correction data: retrieve from W05 decoded from any other satellite or omit at the cost of higher ranging error



Word Type 5: Ionospheric correction, BGD, signal health and data validity status and GST

Type=5	Ionospheric correction								BGD(E1,E5a)	BGD(E1,E5b)	E5b$_{HS}$	E1B$_{HS}$	E5b$_{DVS}$	E1B$_{DVS}$	GST		Spare	Total (bits)
	Az			Ionospheric disturbance flag														
	a_{i0}	a_{i1}	a_{i2}	Region 1	Region 2	Region 3	Region 4	Region 5							WN	TOW		
6	11	11	14	1	1	1	1	1	10	10	2	2	1	1	12	20	23	128

Iono Correction | BGD | Health | GST

Summary

- I/NAV improvement does provide **Improved**
  - **Time to First Fix**
  - **Data Demodulation Robustness**
  - **Time Ambiguity Resolution**
- **Deployment** within Galileo constellation is **completed** – 20 satellites are now broadcasting the improved message on E1-B
- All necessary information for implementation are contained in **Galileo OS SIS-ICD v2.0**
- Benefits
  - **RS-CED** improve TTFF and data error correction
  - **RedCED** greatly improve TTFF as a trade-off with reduced precision

  - **SSP** improves time retrieval in receivers where the system time is coarsely available
- Galileo program does support receiver and chipset manufacturers by "I/NAV improvements implementation testing campaign"

Thank you for your attention!

Questions?