GENESIS

GALILEO INNOVATIVE SPACE SERVICE SOLUTION

Final Report

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CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
1.0	13/03/2019	First issue with FR	F. Paggi

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1. INTRODUCTION

This is the Final Report of the GENESIS (GALILEO INNOVATIVE SPACE SERVICE SOLUTION) project. It describes all work performed and main project outcomes.

1.1. PURPOSE & SCOPE

The document aims to provide the final status of the project.

The approval of the present document will be considered as the overall approval of the Final Review.

1.2. APPLICABLE DOCUMENTS

Acronym	Reference	Issue	Title
[AD 1].	TAS/EU/PRP/061-16-DONI	1.0	GENESIS - GALILEO INNOVATIVE SPACE SERVICE SOLUTION - SECTION IV TECHNICAL PROPOSAL
[AD 2].	537/PP/GRO/RCH/16/9261	N/A	INNOVATIVE MISSION CONCEPTS: R&D FOR A GALILEO SPACE SERVICE - TENDER SPECIFICATIONS

1.3. REFERENCE DOCUMENTS

Acronym	Reference	Issue	Title
[RD 1].	TASI-NVS-PLN-0002-GENS	1.0	GENESIS - Project Management Plan
[RD 2].	N/A	N/A	THE INTEROPERABLE GNSS SPACE SERVICE VOLUME

1.4. DEFINITIONS AND ACRONYMS

Acronym	Meaning
AOC	Autonomous Orbit Control
CSI WG	Compatibility Signal and Interoperability Working Group
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GTO	Geostationary Transfer Orbit
HEO	Highly Elliptical Orbit
HLR	High Level Requirement
ICG	International Committee on Global Navigation Satellite Systems
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
MTO	Medium Transfer Orbit
POD	Precise Orbit Determination
PPP	Precise Point Positioning
PVT	Positioning Velocity and Time
SSV	Space Service Volume
UTC	Coordinated Universal Time

2. WORK STATUS

2.1. STATUS OF THE WORK PERFORMED FOR THE FINAL REVIEW

WP	Title	Status
1000	Management	Coordination of the active WPs Preparation of Final Report
2000	Characterisation of GNSS Space Users and of their Requirements in terms of GNSS	SUR document issue 6 with LEO missions market value; details on user requirements derivation.
3000	GALILEO characteristics relevant to Space Service	Preparation of GSCF issue 6 with derivation of selected user requirements into Mission requirements
4000	Techincal Support to International Coordination on SSV and Awarness	Task completed
5000	Characterization of the emissions of GALILEO satellites exploitable by space GNSS receivers	FSSS issue 4 provided with specific HEO mission analysis as per EC request
6000	Contribution to the definition of G2G Mission and User Level Requirements	Issue of MURD issue 2 with HLR and Mission level requirements
7000	Advanced Signal Processing for GNSS Receivers tailored for space service applications	Completion of WP 7000 tasks Preparation of ASP issue 5

2.2. SUMMARY OF EACH WP OVERALL OUTCOMES

2.2.1. WP 1000 – Management

2.2.1.1. DESCRIPTION OF WORK PERFORMED

The work package provided the key tasks for the project management:

- Different work packages coordination;
- Organization of milestones and delivery of data packages;
- Coordination with EC for the planning of the activities and tuning of the work w.r.t. to the project evolution;
- in general, ensuring the match between EC expectations and Consortium work.

2.2.1.2. MAIN OUTCOMES

The details of the project managing approach have been detailed in the [RD 1] implementing TASI Project Management System, and applying it through the whole project execution; in particular the Project Manager acted also as Technical Manager, ensuring both programmatic and technical control to the activities.

The various milestones and relevant reviews have been run according to [RD 1]; the proactive approach from both Consortium and EC sides allowed to efficiently control both the outcomes and their acceptance by the EC.

2.2.1.3. DELIVERABLES

- D1100 - Project Management Plan (TASI-NVS-PLN-0002-GENS issue 1.0)
- D1201/2/3/4/5 -Progress Reports (TASI-NVS-RPT-0001-GENS, issues from 1.0 to 5.0)
- D1300 - Final Report (TASI-NVS-RPT-0005-GENS issue 1.0)

2.2.2. WP 2000 - Characterisation of GNSS Space Users and of their Requirements in terms of GNSS

2.2.2.1. DESCRIPTION OF WORK PERFORMED

Under WP2000 the study team performed three main tasks:

- Identified, characterised and classified the main GNSS applications in space and determined a potential market demand;

- Performed a targeted stakeholder consultation (in addition, a specific workshop has been held in Bruxelles, in EC premises);

- Identified GNSS space user requirements, for current and foreseen missions.

Based on an in-depth literature analysis along with a focussed stakeholder interviews, a set of user requirements have been identified across different space applications,.
Particularly, over 30 source documents and publications have been analysed. In addition, two web surveys have been designed and run over the course of the assignment: one targeting space players (e.g. mission owners and designers), the other targeting GNSS receiver manufacturers.
Furthermore, the Consortium, as suggested by the Commission, has organised a dedicated user/stakeholder workshop with a selected number of representative target organisations, aimed at finalising and validating the gathered and defined User Requirements.
In total 26 organisations have been consulted during the project, including a representative sample of different key stakeholder categories like space agencies and offices (e.g. ESA, GSA, ASI, CNES, CDTI, FFG and the Estonian space office and the Finnish technology and innovation agency), the European space industry (e.g. the most prominent space systems manufacturers and integrators, and satellite operators in Europe), European GNSS receiver manufacturers and academia.

2.2.2.2. MAIN OUTCOMES

- Besides providing position, navigation, and timing (PNT) services to traditional terrestrial and airborne users, Global Navigation Satellite Systems (GNSS) are also being increasingly used to enable space applications
- The exploitation of GNSS for space applications is therefore an increasing field of interest
- Particularly, the availability of alternative positioning or ranging means in space has a wide range of applications, including for example: precise and autonomous orbit determination, station keeping, launchers trajectory monitoring; rendezvous manoeuvres; formation flying, as well as scientific applications like radio occultation or ocean altimetry. While the need to determine spacecraft position and/or attitude can be performed with other technologies (e.g. earth sensors, ground tracking stations, star trackers, etc.), the use of GNSS can become a competitive alternative, and even replace the traditional methods.

- LEO satellites constitute the majority of forecasted missions and offer the largest market segment for space borne GNSS technology. Nevertheless, applications in GEO missions, as well as in launchers and interplanetary missions are also of growing interest.
- Combining the GNSS space borne receivers' potential target market (including satellites, constellations and mega constellations, launchers, and inter-planetary missions), a potential global market demand of ca. 26350 individual receiver is estimated for the 2017-2036 period.
- Such a growth (average of satellites launched per year in the order of a thousand instead of a hundred when compared to historical data) is mainly driven by the growth of small satellites (<500 kg) in LEO, demanded by an increased number of commercial players wishing to launch constellations and mega-constellations, mainly in the Earth Observation and Telecommunication domains.
- Out of this total market, the target (ideal) European share of the market, has been estimated in over 11,000 space borne receivers (units) and 1.4 billion Euro over 2017-2036 period.
- Based on the literature analysis along the stakeholder consultation, a set of user requirements have been identified across different space applications.
- Main outcome is a comprehensive table of position and timing requirements for all identified mission types.
- The work from this WP allows a proper selection of SSV target requirements for Galileo
- Setting a target for Galileo to meet < =3.5 m (95% sphere, 3D, 95% availability) position accuracy in space will outperform the requirements of most current LEO and GEO missions. Furthermore, such a performance will uniquely satisfy the requirements of LEO satellites in the following market segments:
    - Real Time POD for all Earth Observation missions, including Cubesats;
    - With further investigation (e.g. use of PPP techniques in space), also scientific missions (radio occultation and reflectometry);
    - This level of accuracy is expected to satisfy the need of future mega constellations as well.
- In terms of timing accuracy requirements, the target set to 40 ns (95% confidence, 95% availability) allows to cover all users' needs for LEO missions. It is remarked that the timing accuracy does not include receiver contributions (such as clock calibration).
- Thus, based on the performed market analysis, the above set requirements will target a potential total addressable market for European GNSS space borne receivers of over 5500 units and ca. 0.7 Billion Euro cumulatively in the 2017-2036 reference period.

2.2.2.3. DELIVERABLES

- SUR - Space Users Requirements (STP-GNS-SUR-001, issues 1.0 to 6.0)

- GENESIS Stakeholder workshop report

2.2.3. WP 3000 - GALILEO characteristics relevant to Space Service

2.2.3.1. DESCRIPTION OF WORK PERFORMED

This WP addressed 2 main topics:

- GALILEO Space Service Volume (SSV):

  TAS-I SSV simulator have been implemented and updated according to the inputs made available by EC during the whole project duration. First the simulator has been validated vs. ICG results; in addition the available GNSS navigation antennas pattern (GPS, plus GALILEO FOC made available by EC in the frame of the project) have been included in the simulator in order to assess the possible benefit of side lobes exploitation.

  Specific performances have been derived for different scenarios, including different users' elevation, GNSS constellation (GALILEO only, GALILEO + GPS, and multi GNSS scenarios) and frequencies/services; GNSS constellations orbital parameters have been simulated in order to properly simulate different constellation relative phasing. Also the impact of navigation antennas boresight angles have been assessed vs. the signals availability, along with required users' antenna patterns.

  Finally assessment of the level of availability for the selected targets, on the basis of the outcomes of WP2000, has been performed.

¶ GALILEO ADVANTAGES & GNSS SPACE REC. ADVANTAGES W.R.T. EXISTING SOLUTIONS

  GNSS receiver advantages are examined, comparing them with the existing orbital determination (OD) and orbital navigation (ON) solutions.

  While GPS was in fact a turning point from a 1st generation OD technology to a 2nd generation OD/ON, the enhanced GNSS system reflects a shift to a 3rd generation technology. This mainly happens thanks to the possibility of the GNSS receiver to use the signals provided by the Galileo SVs (E1/E5) leading to a multi-frequency, multi-constellation and multi-antenna receiver architecture. Thanks to these improvements is possible to have a greater accuracy of positioning and an enhanced on-board synchronization capabilities relying on the common stable time reference.

  Furthermore, it will be possible to use this new technology also on innovative platforms (small, agile satellites, etc.) with even more stringent targets.

Moreover, various scenarios are examined, covering the current space service for the different orbits (LEO, MEO, GEO, GTO, etc) and the different types of payloads (telecommunication, observation, etc.). In particular, the approach used provides an explanation of the chosen scenarios with the definition of the main tasks with respect to the requirements, the analysis and comparisons between the existing solutions and the advanced architecture systems and all the implications of the subsystems in terms of performances and capacities.

The analyzed cases are as follows:

- Low Earth Orbit missions scenarios

- Earth Orbit Rising (EOR) and High Orbit missions

- Formation Flying mission scenarios

- Small spacecraft missions

Finally, the meaning of spacecraft attitude in the GNSS enhanced generation is explained, in terms of system architecture and finally what are the implications on spacecraft subsystem performances and capabilities.

2.2.3.2. MAIN OUTCOMES

- Just considering the availability of at least 4 satellites, GALILEO only users could perform a stand-alone positioning with very high availability (above 95% for worst user location) up to 5000 km of altitude; although the PDOP rapidly increases above 4500 km, making the achievable accuracy above 4500 km not fitting the target user needs (<=3.5 m, 95% confidence, 3D sphere, 95% availability).

- GALILEO Space Service Availability is limited w.r.t. to GPS for the lower antenna main lobe aperture; the possibility to increase the main lobe aperture can potentially reduce this gap.

- The exploitation of secondary lobes is of course increasing the GALILEO signals availability at higher elevations; while it is understood that the provision of antenna pattern information to the users will ease GALILEO usage for Space Services, a system level commitment for the ranging performances on the side lobes would be very demanding, also considering the accuracy positioning needs and the constellation geometrical limitation at high elevations.

- Multi GNSS usage is mandatory for user elevations above 8000 km;

- For GEO users, the limitations are first of all related to the signals' availability; therefore, as said before, the use of multi GNSS receivers is therefore mandatory. Also in this scenario, the geometrical limitation (i.e. very poor PDOP) makes difficult to set positioning requirements with adequate accuracy and availability

- Users below 8000 km needs an omnidirectional receiver antenna (note: w.r.t. to the signal reception also 2 antennas, nadir and zenith pointing, could be considered; but the received signals relative calibration w.r.t. power and delays have to be taken into account by the user); geostationary users only need nadir pointing antenna;

- GNSS approach will improve the automation of critical on-board operations and platform performances, enabling also in the next future novel scenarios.

2.2.3.3. DELIVERABLES

- GSCF - GNSS SSV Characterization File (TASI-NVS-TNO-0007-GENS, issue 1.0 to 6.0)

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2.2.4. WP 4000 - Technical Support to International Coordination on SSV and Awareness

2.2.4.1. DESCRIPTION OF WORK PERFORMED

This WP foresaw support to EC for international SSV coordination activities; while no formal deliverables have issued, ad-hoc support related to SSV has been required and provided:

- Support to ICG outcomes review;

- Contribution to European Radio Navigation Plan;

- Participation to CSI WG with contribution on GNSS Spaceborn receivers state-of-the-art;

- Project presentation for ICG;

- Support to the definition of user error budget for different scenarios (eventually included in the MURD document).

2.2.4.2. MAIN OUTCOMES

N/A

2.2.4.3. DELIVERABLES

- GENESIS Project (ICG presentation)

- CSI WG GENESIS (CSI WG presentation)

- GENESIS - CS2 – Coverage (ERNP contribution for SSV)

2.2.5. WP 5000 - Characterization of the emissions of GALILEO satellites exploitable by space GNSS receivers

2.2.5.1. DESCRIPTION OF WORK PERFORMED

The work performed focused mainly on 2 subjects:

- Payload definition
- Missions analysis

Regarding Payload definition to characterize Galileo emissions, the following tasks have been completed:

A hosted payload has been designed for single and multiple bands reception. Preliminary antenna definition and accommodation, and the related link budget have been performed. Considering typical components for such type of payloads, a MVC (Mass Volume Consumption) budget has been calculated for both approaches, including redundancies.

Concerning the mission, the following possibilities have been analysed:

- GEO mission
- LEO to GEO mission
- HEO mission
- MEO mission
- LEO to MEO mission

For each case, the orbital parameters have been studied with respect to GALILEO orbital planes, thus determining the visibility angles between the satellites (line of sight / field of view) during the simulation times. Considerations on antenna accommodation have been taken into account. Statistics on the view angles have also been derived.

2.2.5.2. MAIN OUTCOMES

Concerning the payload, to be hosted on another mission, two technologies have been considered: the transparent payload, where the signal received from the GALILEO satellite is sent back to Earth “as is”, without processing and the regenerative payload, where the signal is demodulated, pre-processed and modulated before being transmitted to the Ground Station. The transparent approach could be a better candidate for the characterization of GNSS antenna pattern. Its simpler architecture and reduced Mass, Volume and Consumption budget make it more suitable for a hosted payload while allowing a more powerful and customizable signal processing at Ground Stations.

A trade-off on missions in terms of their efficiency in GNSS pattern characterisation, showed that:

- LEO to MEO mission with electrical propulsion provides a long survey time with fine angular resolution, thanks to the slow altitude increase and the constant RAAN variation
- MEO mission brings the advantage of a characterisation within the GALILEO system, thus making the characterisation process independent from external factors and other missions
- HEO mission offers countless possibility in terms of orbital parameters, thus allowing multiple possibilities of characterization
- The additional analysed HEO mission (Apogee about 40000 km, Perigee about 8000 km) proved to be a good candidate for GNSS antenna characterisation, particularly for GALILEO satellites on B and C planes. Thanks to the relative orbit drift, a high angular resolution can be achieved with a long time measurements.

2.2.5.3. DELIVERABLES

- FSSS - Feasibility Study for SSV Characterisation from Space (0005-0009416626, issue 1.0 to 4.0)
- “LEO-MEO Transfer GNSS space service characterization” (0005-0009894733 issue 1.0)

2.2.6. WP 6000 - Contribution to the definition of G2G Mission and User Level Requirements

2.2.6.1. DESCRIPTION OF WORK PERFORMED

This WP collected the outcomes of WP 2000 and 3000 in order to derive G2G Mission Level requirements for Space Service.

At first step, High Level Requirements have been derived, in order to define the target for GALILEO Space Services: together with EC, the GALILEO added value has been identified in the standalone PVT services at lower elevations, and the contribution to positioning for geostationary users. As already said, this scenario requires multi GNSS receivers.

As second step, the HLR have been flown down as mission level requirements, following similar approach for other GALILEO mission level requirements. For each target service requirements have been derived in terms of target performances, availability, user requirements, minimum power, and GALILEO user antenna aperture.

For multi constellation scenarios, the approach recommended by ICG [RD 2] has been followed.

Finally the user ranging error budget considered for deriving the performances is presented and justified.

2.2.6.2. MAIN OUTCOMES

GALILEO Space Service Volume requirements address to:

- **Positioning accuracy** of 3.5 m (3-D, 95% confidence) up to 4500 km of altitude, with 95% availability (for dual frequency users)
- **UTC estimation accuracy** of 40 ns (95% confidence, excluding receiver contribution) up to 4500 km of altitude, with 95% availability (for single/dual frequency users)
- **Single satellite link availability** for geostationary users greater than 60% (contributing to multi GNSS multisatellite availability)

2.2.6.3. DELIVERABLES

- MURD - G2G Mission and User Level requirements (TASI-NVS-URD-0001-GENS issue 1.0 and 2.0)

2.2.7. WP 7000 - Advanced Signal Processing for GNSS Receivers tailored for space service applications

2.2.7.1. DESCRIPTION OF WORK PERFORMED

- Receiver Signal Processing Techniques for Space Service

The signal processing techniques analysed in this WP have been mainly focused on fast and robust weak signal acquisition, weak-signal navigation data retrieval and interference mitigation. For each task under study, the proposed algorithms and the related simulation assumptions have been driven by GNSS Spaceborne Receiver current architecture impacts/limitations, with an eye on the possible future evolutions on receiver technology.

Fast and Robust Signal Acquisition

Concerning GNSS high sensitivity signal detection and acquisition, the Serial Search Acquisition technique has been analysed in relation with weak signal acquisition and the high dynamic conditions applicable to several space mission applications (LEO, GTO/HEO and HEO-Moon, thus three different C/No levels). The signals considered are GPS L1C/A, L5 and GALILEO E1 B/C and E5a, most likely the ones that will be "universally" used as dual-frequency GNSS in space. For each application, the signal detection/acquisition performances have been evaluated in terms of signal detection time w.r.t. a probability of false alarm and through the Cold (no a-priori information) and Warm acquisition (with aiding information) cases. The analysis provides an overall view of the acquisition performance in space and confirms suitable performance for a SSV application[1]: the modernized GNSS signals, such as GALILEO SIS, provide interesting results when aided acquisition strategies are taken into account (especially when an high sensitivity detection is required.

[1] with a notable exception: the case of cold start.

Navigation Message Decoding

This task has been focused on GALILEO E1B component (I/NAV message). A SW Viterbi Decoder (VD) has been analysed (in the assumption of no dedicated HW on which to carry out the task, like the ESA's AGGA-4 correlator). This implementation strategy provides a lower performance wrt a large decision depth, HW implementation. This technique results efficient in high link budget conditions (C/No > 30 dB-Hz), while in medium-low C/No values the proposed SW VD performance are degraded. In this case, a methodology to improve the SW VD performance was proposed, based on Majority Voting (MV). Despite an increment of the latency and a computational cost increment this technique allows to achieve a performance similar to a VD in HW.

Interference Suppression

The interference cancellation techniques provide an efficient approach to the weak signal processing when the near-far problem is present (i.e. GTO, MTO, HEO missions). DIPC algorithm (Glennon 2007) has been studied and considered as the most promising one for the interference mitigation in space context (post-correlation processing). Its implementation has also been evaluated w.r.t. the current GNSS Rx architecture for space applications showing that the natural execution environment is a reconfigurable correlator (for example in FPGA) and not in a monolithic channel processor.

The work focused on two GPS signals present: one attacker and one weak signal. The preliminary simulation results confirm that, without a proper mitigation strategy, the strong signal (SI) leaks into the weak one, causing spurious detection of the weak. Thanks to the slaving channel approach present in DPIC, a SI regeneration has been implemented and its results have been compared with SI and WI in order to derive the scaling factor for the cleaning signal step. Future works will be the implementation of the last steps (clean correlators) of DPIC technique.

- Positioning techniques for Space Service

The PVT evaluation in this WP has been carried out for five mission selected scenarios:

1. LEO Agile satellite
2. Formation flying
3. LEO to MEO orbital transfer
4. LEO to GEO orbital transfer
5. LEO Small satellite

As agreed with EC, for each of these scenarios a preliminary analysis has been achieved whereas a detailed analysis has been carried out for the cases 1,3,5.

Preliminary error budget

For what concerns the preliminary error budget, a method that provides a first order position, velocity and time accuracy estimation for target GNSS application was used. It is based on the evaluation of the UERE/UERRE and the PDOP factor considering the orbit altitude, the receiver design (i.e. availability of a Multifrequency, Multiconstellation o Multiantenna solution) ,hardware configuration, as well as observation combination (ionofree, zero-difference- double-difference, etc.) The performance indexes assessed are related to an unfiltered solution, and a filtered solution with two filter configuration.

Detailed analysis

This kind of analysis has been carried out through the TAS-I SW tool MEONS and for each scenario a simulation time covering the whole GNSS constellation period was selected. An evaluation of the position and velocity errors variation with respect to time was conducted, relating it with a visibility analysis of the GNSS satellites. In this way a comparison among possible issues of each scenario has been achieved, especially for what concerns the following aspects:

- The GNSS configuration: Galileo or Galileo and GPS
- The spacecraft altitude
- The control law adopted(LEO cases)
- The single or multi-antenna configuration

The LEO to MEO transfer was tested with only three different altitudes due to time constraints, as agreed with EC.

2.2.7.2. MAIN OUTCOMES

- The lack of a “coarse/acquisition” signal in GALILEO is seen as a major disadvantage of GALILEO w.r.t. GPS for a SSV User when no a-priori information are available to the receiver (i.e. cold start).
- The DIPC interference cancellation appears to be a promising technique for Space applications, where near-far issues can be treated in a similar way.
- PVT simulations show that when the number of satellites in visibility is enough to use the filtering mode, the position and velocity errors are in the order of meters in all cases, according to the MURD target requirements. Moreover, most critical GNSS visibility issue is presented in the highest orbit of the LEO to MEO transfer, leading to the biggest position and velocity errors.

2.2.7.3. DELIVERABLES

- ASP - Advanced Signal Processing for Spaceborn Receivers (TASI-NVS-TNO-0009-GENS issues 1.0 to 4.0)

2.3. LIST OF PROBLEMS, LIMITATIONS OR UNEXPECTED POINTS

- The Antenna characterization foreseen in WP 5000 could not be completed due to hardware availability limitations. As per agreement with EC, the activity effort has been agreed to be devoted to additional analyses regarding the Galileo characterization through a HEO mission.

- The completion of WP 2000 took longer than expected; this was mainly due to the difficulties to receive prompt reactions from the relevant stakeholders. The issue has been partially mitigated by the organization of the "Workshop on G2G user requirements", which was not originally foreseen; but it impacted the overall completion of subsequent activities.

2.4. COORDINATION ISSUES

No specific issues to be raised.

3. LIST OF DELIVERABLES

3.1. SUBMITTED FOR THE PM

GENESIS reference	Title	Document Reference number	Issue
D1300	Final Report	TASI-NVS-RPT-0005-GENS	1.0
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	6.0
FSSS	Feasibility Study for SSV Characterisation from Space	0005-0009416626	4.0
ASP	Advanced Signal Processing for Spaceborn	TASI-NVS-TNO-0009-GENS	5.0

	Receivers		
SUR	Space Users Requirements	STP-GNS-SUR-001	6
MURD	G2G Mission and User Level requirements	TASI-NVS-URD-0001-GENS	2.0
MURD	G2G Mission and User Level requirements	TASI-NVS-URD-0001-GENS	3.0

3.2. DELIVERABLES FROM THE START OF THE PROJECT

GENESIS reference	Title	Document Reference number	Issue	Date
D1100	Project Management Plan	TASI-NVS-PLN-0002-GENS	1.0	27/10/2017
D1201	Progress Report	TASI-NVS-RPT-0001-GENS	1.0	27/10/2017
D1202	Progress Report	TASI-NVS-RPT-0001-GENS	2.0	07/02/2018
D1203	Progress Report	TASI-NVS-RPT-0001-GENS	3.0	18/05/2018
D1204	Progress Report	TASI-NVS-RPT-0001-GENS	4.0	18/10/2018
D1205	Progress Report	TASI-NVS-RPT-0001-GENS	5.0	13/12/2018
D1300	Final Report	TASI-NVS-RPT-0005-GENS	1.0	13/03/2019
SUR	Space Users Requirements	STP-GNS-SUR-001	1	13/10/2017
SUR	Space Users Requirements	STP-GNS-SUR-001	2	30/10/2017

SUR	Space Users Requirements	STP-GNS-SUR-001	3	18/06/2018
SUR	Space Users Requirements	STP-GNS-SUR-001	4	17/09/2018
SUR	Space Users Requirements	STP-GNS-SUR-001	5	14/12/2018
SUR	Space Users Requirements	STP-GNS-SUR-001	6	21/02/2019
N/A	Stakeholder Workshop Report	N/A	1	20/07/2018
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	1.0	13/10/2017
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	2.0	07/02/2018
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	3.0	18/05/2018
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	4.0	18/10/2018
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	5.0	13/12/2018
GSCF	GNSS SSV Characterization File	TASI-NVS-TNO-0007-GENS	6.0	13/03/2019
AGSC	Advanced Galileo SSV Characterisation	TASI-NVS-TNO-0008-GENS	1.0	07/02/2018
MURD	G2G Mission and User Level requirements	TASI-NVS-URD-0001-GENS	1.0	18/05/2018
MURD	G2G Mission and User Level	TASI-NVS-URD-0001-GENS	2.0	13/03/2019

	requirements			
ASP	Advanced Signal Processing for Spaceborn Receivers	TASI-NVS-TNO-0009-GENS	1.0	18/05/2018
ASP	Advanced Signal Processing for Spaceborn Receivers	TASI-NVS-TNO-0009-GENS	2.0	05/09/2018
ASP	Advanced Signal Processing for Spaceborn Receivers	TASI-NVS-TNO-0009-GENS	3.0	19/10/2018
ASP	Advanced Signal Processing for Spaceborn Receivers	TASI-NVS-TNO-0009-GENS	4.0	30/11/2018
ASP	Advanced Signal Processing for Spaceborn Receivers	TASI-NVS-TNO-0009-GENS	5.0	31/01/2019
FSSS	Feasibility Study for SSV Characterisation from Space	0005-0009416626	1.0	10/04/2018
FSSS	Feasibility Study for SSV Characterisation from Space	0005-0009416626	2.1	03/08/2018
FSSS	Feasibility Study for SSV Characterisation from Space	0005-0009416626	3.0	13/12/2018
FSSS	Feasibility Study for SSV Characterisation from Space	0005-0009416626	4.0	04/02/2019
N/A	LEO-MEO Transfer GNSS space service	0005-0009894733	1.0	20/08/2018

	characterization			

4. MEETINGS ATTENDANCE

4.1. MEETINGS ATTENDANCE FROM THE START OF THE PROJECT

Meeting	Date	Location
KOM	01/06/2017	Bruxelles (Belgium)
Progress Meeting 1	19/09/2017	Ispra (Italy)
Progress Meeting 2	12/12/2017	Teleconf
Progress Meeting 3	21/03/2018	Brussel, Belgium
Workshop on G2G user requirements	20/03/2018	Brussel, Belgium
Progress Meeting 4	26/06/2018	Rome, Italy
Progress Meeting 5	16/11/2018	Rome, Italy
Final Review	17/12/2018	Teleconf

5. RISK REGISTER

At Final Review the Risk Register has been closed.

6. ACTION ITEMS LIST

AI#1	CONTEXT	Originator	Description	Responsible	Progress	Status	Due date
1	KOM	EC	TASK 2 - To provide to EC the list of of organizations/stakeholder to be interviewed	SpaceTec - C. Filotico	Feedback provided by C. Filotico by mail on 04/08	Closed	26/07/2017
2	KOM	EC	TASK 2 – To provide feedback on the possibility to organize dedicated workshop with ESOC navigation for space user needs.	SpaceTec - C. Filotico	Feedback provided by C. Filotico by mail on 04/08	Closed	26/07/2017
3	KOM	EC	TASK 3 – to held a teleconf EC/TASI on the SSV scenarios for GSCF issue 1	TASI - F. Paggi	Scenarios list agreed as per 19/06 teleconf and subsequent mail	Closed	16/06/2017
4	KOM	EC	TASK 5- TAS-I to provide a list of G1G documents where navigation antenna file are contained	TASI - F. Paggi	Document list provided via mail on 19/06/2017	Closed	26/07/2017
5	KOM	EC	TAS-I to provide a feedback on the EC proposal for review meeting organization	TASI - F. Paggi	Proposed approach documented in PMP document	Closed	26/07/2017

6	KOM	EC	TAS-I to contact Peter Grognard and to clarify to EC his role inside the projects	TASI - F. Paggi	Mr. Grognard involvement has been confirmed	Closed	26/07/2017
7	PM1	TASI	EC to finalize GALILEO FOC antenna model vs. SVID allocation data retrieval.	EC	EC still to provide feedback; anyway GSCF issue 2 demonstrated that the allocation impact is negligible	Closed	16/10/2017
8	PM1	TASI	EC to provide contact point for formal data delivery	EC	Contact point provided by J.P. Boyero on 26/09	Closed	16/10/2017
9	PM1	TASI	EC to provide GALILEO IOV antenna patterns.	EC	As per agreement shared with EC on 17/07/2018	Closed	16/10/2017
10	PM2	EC	STP to provide the list of the potential participants to the workshop, highlighting mandatory and not mandatory participants	STP		Closed	18/12/2017
11	PM2	EC	To regularly keep EC informed on the status of the interview	STP	Task completed	Closed	Until interviews completion

12	PM2	EC	TASI to organize teleconf between STP and EC (in particular J.P. Boyero) to highlight the status of the survey and to agree on potential actions to enhance stakeholders' Awarness on the activity (Target: start of CW 51 2017)	TASI		Closed	15/12/2017
13	PM2	TASI	to provide to the consortium the ICG multi-SSV booklet to confirm SSV simulator	EC	Provided at PM3	Closed	15/01/2018
14	PM2	TASI	EC to check if IOT data (e.g. test reports) are available to refine Correlation Losses assumptions	EC	As per agreement shared with EC on 17/07/201	Closed	15/01/2018
15	PM2	EC	TAS-F to explore GTO to MEO orbit transfer as possible spaceborn GNSS antennas characterization scenario	TASF	As per MoM of PM3, the action has been reflected in LEO-MEO transfer orbit (included in section 7 of FSSS)	Closed	PM4
16	PM2	EC	To provide expected Workshop attendance	STP		Closed	19/12/2017

17	PM2	EC	EC confirm the workshop/PM3 dates and take care of the logistic	EC		Closed	22/12/2017
18	PM2	EC	STP to provide workshop draft invitation letter and agenda	STP		Closed	21/12/2017 EoB
19	PM2	EC	To update the SSV simulator to include averaged antenna pattern for IOV satellites; to provide availability figures for exsisting scenarios	TASI	Implemented in GSCF issue 3	Closed	PM3
20	PM3	EC	Update SUR with survey/workshop outcome	STP	Completed	Closed	19/04/2018
21	PM3	EC	To provide feedback on update planning	TASI	Completed	Closed	06/04/2018
22	PM3	EC	To request ESA on on-ground antenna characterization at satellite level	EC	Document provided by EC	Closed	29/03/2018
23	PM3	EC	To confirm Free Space Loss Figures provided in FSSS presentation	TAS-F	Correct value reported; presentation updated and shared; correct value to be reported in FSSS issue 1	Closed	27/03/2018

24	PM3	TASI	To provide FOC I/NAV optimization documentation – specifically, FEC2 Reed-Solomon pages TN	EC	Closed in favour of other ASP activities	Closed	27/03/2018
25	PM4	EC	To provide a summary of the pending EC actions and their potential impact on the programme completion; after it, action will be considered to be closed	TASI		Closed	17/07/2018
26	PM4	EC	To complete workshop report	STP		Closed	20/07/2018
27	PM4	EC	1. To Update the document with the PDOP values relevant to the antenna aperture sensitivity analysis 2. To provided, along with the gap analysis, a list of the system assumption considered (ranging accuracy, etc.)	TASI		Closed	20/07/2018
28	PM4	EC	To prepare with paper with availability sensitivity analysis	TASI	No updates on this activity	Closed	TBD

29	PM4	EC	To provide feedback on the possibility to characterize the E5-E6 frequencies with the same reception chain	TASF		Closed	20/07/2018
30	PM4	EC	to contextualize in the FSSS document the proposed space mission (i.e. summarizing advantages/benefits in terms of Space Services)	TASF		Closed	PM4 CO
31	PM5	EC	To report weekly on the HGA antenna status	TASI		Closed	FR
32	PM5	EC	ASP (signal processing) To provide Probability Error comparison between Hard decision and soft decision (and associated computational burden)	TASI	Closed as best effort activity into ASP issue 6	Closed	FR KO
33	PM5	EC	ASP (PVT) to provide planning of simulation for the remaining of the activity	TASI		Closed	23/11/2018
34	FR	EC	To provide feedback on receiver UERE contribution	TASI	Provided by mail on 11/01/2019	Closed	10/01/2019

7. LESSONS LEARNT AND RECOMMENDATIONS FOR FUTURE WORK

- Space Service Users are very interested in the availability of GNSS navigation antennas pattern information. While this information can be used at system level to derive expected performances and derive commitments, this information is understood to be essential to be shared with user community, therefore providing this information will grant advantage to GALILEO usage; Specific mission level requirement has been derived on this aspect.
- Within the possible space-based missions to characterize the GALILEO antennas, the use of a LEO-to-MEO transfer orbit appears promising: due to mission duration RAAN variation and slow altitude increase provide respectively a Line of Sight on a wide Field of View and a high angular resolution. The additional analysed HEO mission proved to be also a good candidate for GNSS antenna characterisation, particularly for GALILEO satellites on B and C planes. Additional work (e.g. analysis covering detailed satellite attitudes and antenna positioning) are envisaged; Thanks to the relative orbit drift, a high angular resolution can be achieved with a long time measurements.
- The main limitation of GALILEO vs. GPS for high elevation Space Services is the limited antenna boresight angles (3° differences for GALILEO w.r.t. GPS L1C/A); specific design drivers for G2G could be antenna aperture relaxation or the definition of a specific antenna pattern for space users; additional work can focus on the definition of specific antenna patterns
- It is recognized that the current GALILEO signal design is not optimized for Space Services, both in terms of PRN codes length and modulation. Results show the current gap of GALILEO w.r.t. GPS for acquisition: the possibility to address specific future work on dedicated signal component definition is recommended.

END OF DOCUMENT