

Report of Working Group B: Enhancement of GNSS Performance, New Services and Capabilities

1. The Working Group on Enhancement of GNSS Performance, New Services and Capabilities, co-chaired by the European Space Agency (ESA), China and the Indian Space Research Organization (ISRO), held its twelfth annual meeting in Kyoto, Japan, between 4 and 6 December 2017, preceded by a dedicated session on Space Service Volume (SSV).

2. During the dedicated meeting on the subject of establishing an interoperable GNSS Space Service Volume (SSV) the SSV booklet DRAFT was reviewed in detail, including the results of the supporting simulations. Joint simulations conducted by the group for multiple mission profiles provide clear evidence that for space users at high altitude no single constellation is able on its own to provide a sufficient level of GNSS signal availability. The Work of the WG-B related to the GNSS Space Service Volume (SSV) and its promising outcomes demonstrated the importance and relevance of the interoperability of GNSS.

The excellent cooperation among all members of the SSV action team allowed to prepare a final draft of the SSV booklet that is submitted to the ICG and GNSS Providers for endorsement. Following the endorsement of the SSV booklet the publication is targeted to be in time for the fiftieth anniversary of the first UNISPACE conference.

The work of WG-B indicated very clearly the significant value of GNSS SSV for a much wider scope of future space exploration activities of various nations around the world.

Additional ideas have been discussed in the Working Group which will be considered for future activities of the WG-B on the SSV. Beyond the publication of the ICG SSV booklet, Members of Working Group B will conduct outreach activities on the interoperable GNSS SSV, conference sessions and papers together with supporting illustrative video material will be prepared.

During the dedicated SSV session, the WG reviewed the storybook and animation sequences for an illustrative video prepared by NASA based on the contributions and comments received from the members of WG-B. The objective of this video is to promote the Interoperable GNSS SSV together.

The WG also discussed outreach activities to raise awareness about the benefits of the interoperable Space Service Volume and to promote the prepared booklet. Among the opportunities identified are a Panel Discussion on SSV as part of the SATELLITE 2018 conference, in March 2018 in Washington, D.C. Furthermore, it was agreed to assess the possibility to organise dedicated SSV panels and keynote presentations at ION GNSS+ 2018, CNSC 2018 and IAC 2018. The group agreed to prepare a paper on the Interoperable SSV to be presented to the SpaceOps 2018 conference taking place in Marseille.

GNSS SSV and potential augmentations can be seen as an enabler for many ambitious missions and activities in the context of space exploration going beyond low Earth orbit to the Moon, Mars and other celestial bodies. The WG-B noted that new concepts such as the Deep Space Gateway, could use the SSV capability to serve humankind in its next phase of space exploration.

3. At the 12th annual meeting of WG-B the following presentations were given and discussed:
 - (a) The Application Subgroup, established within WG-B and co-chaired by China and Japan, presented its latest work resulting in an updated electronic questionnaire which has been made available at ICG-12. This questionnaire will be used to collect initial feedback on future GNSS user needs. ICG participants are invited to fill the questionnaire in order to provide feedback and guidance to the work conducted by the Application Subgroup in its collection of future user needs specific to different application domains including among others personal navigation, timing, agriculture and disaster management. The questionnaire is available under the following link: <http://121.42.29.87/index.php/377458?lang=en>.
The plan of the sub-group is to further develop the electronic version of the questionnaire in multiple languages and complement these with paper versions. The group also plans to reach-out to user communities by distributing the questionnaire through various conferences and through the ICG website. An initial report on the collected feedback from the questionnaire is anticipated for the next ICG-13 meeting.
To achieve this goal the Co-Chairs of the subgroup requested to members of the ICG, to identify organizations in charge to cooperate within the sub-group with the objective share the

questionnaire, collect and analyse answers, and contribute to the 1st draft of user requirement report.

Following the ICG-11 request for contributions to Space Weather, Remote Sensing and Scientific Applications, the WG-B meeting during ICG-12 has received four interesting contributions to this topic. The importance of this activity is shared within the working group.

- (b) The National Institute of Information and Communications Technology (NICT), Japan, presents to the WG the benefits of the high-resolution TEC observations using dense GNSS receiver networks as a tool to monitor and research ionospheric space weather phenomena such as ionospheric storm, plasma bubble, and traveling ionospheric disturbances. As part of the briefing the DRAWING-TEC project (Dense Regional and Worldwide International GNSS-TEC observation) is presented. The project intends to expand the observation area of high-resolution TEC maps through international exchange of GNSS and TEC data based on a new exchange format, GTEX, which has been approved as one of the standard formats in the ITU-R P.311 recommendation. NICT also introduces the WG to a new universal ionosphere storm scale, I-scale, and a new Ionospheric storm monitoring system using real-time TEC observations in Japan.
- (c) The Chinese Academy of Sciences (CAS) presents the operational space weather services used to monitor, specify, and forecast space weather in order to provide timely, accurate, and reliable services for Chinese national infrastructure. The CAS joined the IGS analysis centres in routinely generating accurate and reliable ionosphere maps of Total Electron Content (GIM). The Beidou Ionospheric Observation Network is using BDS ionospheric monitors to provide dense and continuous TEC observations. Regional TEC maps with high resolution, for China and adjacent areas, are constructed based on the CMONOC and SEMnet/Meridian Project networks allowing ionospheric error correction for the BDS/GNSS system. High-resolution ROTI maps (Rate of TEC Index) derived from dense BDS/GNSS networks have been built to represent the regional ionosphere irregularities and radio scintillations. Space Weather awareness is improved by statistical analysis of past anomalies detected in Beidou satellites and the prediction of future events and radiation event warnings for Beidou MEO/IGSO/GEO satellites provided by Space Weather situation awareness picture (SWASP). CAS presents the space weather monitoring payload of Beidou IGSO satellite, which used to study relativistic electron injection during geomagnetic sub-storm events.
- (d) NASA Jet Propulsion Laboratory/ California Institute of Technology provides a briefing on GNSS-Reflectometry (GNSS-R), a new remote sensing technique using GNSS signals reflected on the Earth's surface. The reflected GNSS signals are exploited by airborne or space-based systems. GNSS-R offers many unique advantages compared to other remote sensing techniques, such as multiple and simultaneous observations with high spatial/temporal coverage, especially when using the free high-quality signals from multiple GNSS. This technique has been demonstrated successfully in several research areas, such as Ocean winds, soil moisture, wetland extent, freeze-thaw state, sea ice extent, ocean altimetry. This is enabled by the space-based GNSS-R mission launched in the recent years – TDS1, SMAP and CyGNSS – with lead to an explosive increase of available observation data.
- (e) The European Space Agency (ESA) reports on the status of gravitational redshift tests conducted with Eccentric Galileo Satellites. Two Galileo satellites were injected into an eccentric orbit in 2014 due to an anomaly of the launch vehicle upper stage. The high eccentricity of the resulting orbit together with the highly stable on-board Passive Hydrogen Maser clocks allows to test interesting features related to General Relativity, especially on the so-called gravitational redshift. ESA presented first results of the study showing an improvement of the General Relativity Gravitational redshift by a factor of 3 with respect to measurements available up to now, down to a value of 4.4×10^{-5} using eccentric Galileo satellites. Further general relativity study subjects have been identified.

Two contributions have been received to support discussion in the area of Interoperable GNSS Space Service Volume.

- (f) NASA reports to the working group on “NASA GNSS Activities”. NASA is engaged in numerous space-critical GNSS initiatives that are bearing great fruit for future missions and additional PNT capability. Some of these activities (e.g. GARISS) represent outstanding USA/international partnerships that will extend our GNSS understanding and signal utility. NASA presents the Magnetospheric Multi-Scale mission which consists of four spacecraft in highly eccentric orbits measuring Earth’s magnetosphere. GPS receivers on-board achieved records for the highest GNSS signal reception and the fastest operational GPS receiver. NASA reports on the signature of a Memorandum of Understanding between NASA and USAF with the intention to ensure SSV signal continuity for future civil space users. NASA introduces the Next Generation Broadcast Service as a potential supplement to GNSS in the SSV improving resiliency. NASA is seeking stakeholder feedback on which NGBS services would be beneficial for their use cases. The Automatic Flight Termination System (AFTS) is a means to improve Launch Range use, to reduce launch costs and improve the safety of people and property. To achieve this the AFTS is relying on GPS/IMU sensors.
- (g) JAXA presents on the Japanese development of a High Altitude GNSS Receiver with specialised software and improved sensitivity for GEO use case. JAXA introduces the plan for demonstrating the capabilities through experimentation in GEO in 2019 and with expected practical application of the receiver in 2021. JAXA emphasises the importance of GNSS signal information (such as antenna patterns or signal levels including side-lobes, etc.) to current and future space missions taking benefit of GNSS signals in the SSV. JAXA also recommends to establish SSV signal specifications in the signal interface specification documents to support the GNSS receiver development for the SSV. The importance to maintain the SSV signal environment in support of for future new space missions using GNSS navigation in high altitude orbits is also highlighted.

Regarding the work area of novel user position integrity models and solutions one presentation was given.

- (h) The National Institute of Maritime, Port and Aviation Technology, Japan, presents results of the first experiment on Dual-Frequency Multi-Constellation SBAS demonstration via QZSS L5S Signals transmitted from GEO and IGSO. The Electronic Navigation Research Institute (ENRI) has developed the prototype DFMC SBAS in compliance with the draft ICAO DFMC SBAS standards. The prototype is GPS, GLONASS and Galileo capable. The DFMC SBAS experiment has been conducted since 23 August, 2017. The results show improvements in terms of GNSS accuracy and integrity with the SBAS corrections.

Three presentations were provided to brief the working group on recent evolutions on Search and Rescue.

- (i) The European Commission (EC) presents on the Search and Rescue Service (SAR) Status in Galileo. The SAR Service in Galileo consists of two distinct elements, the Forward Link Alert Service as a contribution to the Cospas-Sarsat MEOSAR programme and the Return Link Alert Service, which provides to users in distress an acknowledgement message informing them that the alert has been detected and located. The forward link is according to Cospas SARSAT standard with uplink at 406.05 MHz and downlink at 1544.1 MHz. Three Medium Earth Orbit Local User Terminals (MEOLUT) cover the SAR areas over Europe. The return link service is a unique Galileo feature using the Galileo E1 navigation message for broadcasting the acknowledgment messages. A significant step on the Galileo/SAR service was achieved with the declaration of Galileo Initial Services by end 2016.
- (j) The China Transport Telecommunications & Information Centre presented the plans and current status of the BDS Search and Rescue Payload. BDS plans to provide the SAR service in near future by deploying SAR payloads on 5 to 6 satellites during 2018-2020, with the first SAR payload planned to be launched in 2018. The payload will support two SAR functions. On the one hand the transfer the distress signal to MEO Local User Terminals (MEOLUT) by receiving, filtering and transmitting the signals. And on the other hand, support the localization of the distress user based on stable and accurate frequency conversion and accurate satellite orbit and time synchronization. In Oct., 2017 during the 31th meeting, COSPAS-SARSAT agree the BDS SAR payload to join the MEOSAR test plan. Further

collaboration and coordination is necessary in the framework of COSPAS-SARSAT, e.g. to define the downlink frequency of the global service. BDS commits to join the MEOSAR, to add the SAR payload and to finish the ground segment construction.

- (k) NASA provides a briefing from the 31st Joint Commitee meeting of COSPAS SARSAT on the evolutions of the MEOSAR Space Segment, the Interoperability of the MEOSAR signals and the Return Link Service. In addition to Signal improvements of interoperability on signal level, another mitigation to possible interference was identified to be achieved with optimised MEOLUT tracking plans avoiding tracking satellites during conjunctions. NASA presents a summary of an analysis carried out in the early 1990s on the subject, that show this a possible mitigation. The WG-B agreed to continue to assess the interoperability specifications at COSPAS-SARSAT level in line with WG-B work plan. The signal level interoperability of the SAR downlink signals was agreed to be followed up by the Compatibility & Spectrum Sub-Working Group of WG-S during the inter Working Group coordination.

In support of discussion in the area of Enhancement of GNSS signals, performance and System enhancements two presentation have been given to the working group.

- (l) The University of Tokyo, Japan, presents on the risks of spoofing of GNSS signals and the advantages the authentication of the GNSS signals can provide to users. The concept of providing digital signature data as part of the QZSS Navigation Message is introduced. First demonstration results indicate that the QZSS Signals can be used to authenticate GPS and QZSS Signals. The authentication of other GNSS signals is also possible. A recommendation is given to further discuss Spoofing, Anti-spoofing and Authentication in future ICG meetings.
 - (m) The NTT Corporation, Japan, presents on Precision Improvement in GNSS Time Synchronization by mitigating the effect of multipath signals from Non-Line Of Sight Satellites (NLOS). The presentation identified the challenges of high precision timing applications when using GNSS signals in urban environments. Especially the impacts of SIS diffraction and reflection are addressed. The results of a study are highlighting the benefits of using NLOS satellites in environments with less than 4 LOS satellites – especially those NLOS satellites suffering only for lower propagation delays. The challenges of the statistical selection of NLOS satellites are presented together with promising results showing the feasibility of this concept for stationary and dynamic receivers.
4. The progress of ICG-11 recommendations is assessed.
- The updated work-plan as endorsed during ICG-10 is in place and is followed up. Several contributions on the new topic of Space Weather Aspects and GNSS-Reflectometry have been made during the WG-B meeting. In order to ensure further progress, continued support from Providers and Space Agencies is required to establish a good dialogue among experts in the field.
 - The recommendation related to the use of GNSS satellites in eccentric, non-nominal orbits for scientific experiments is followed up and initial experimental results were presented.
 - The recommendations from ICG-11 are followed up. Especially for Recommendation 3, additional information provided by Russia during the interim meeting has enabled to complete the simulations for the SSV booklet.
5. WG-B plans to organise at least one WG-B Interim Meeting in June 2018 in conjunction with the ICG-13 Preparation meeting in Vienna with particular focus on SSV, SAR, Future Integrity Concepts and Emergency Warning Services. The need for a second meeting was identified to allow to focus on Space Weather, Scientific Applications of GNSS signals such as Radio Occultation.

ATTACHMENT 1.1

WG-B Recommendation 1 Endorsed by Committee Decision

Prepared by: Working Group B

Date of Submission: 6 December 2017

Issue Title: Search and Rescue GNSS payload interoperability

Background/Brief Description of the Issue:

The space segment component of the international Search and Rescue program is expanding. This requires continued communication between the GNSS providers to ensure interoperability.

Discussion/Analyses:

Information sharing has deepened to better understand the service providers' search and rescue concept of operations using GNSS payloads. Near-term intentions of the newest SAR space segment provider, BDS, was discussed.

Recommendation of Committee Action:

Invite further discussions on the global interoperability of search and rescue payloads on board GNSS constellation spacecraft. This includes national and international coverage concepts as well as return link implementation progress.

ATTACHMENT 1.2

WG-B Recommendation 2 Endorsed by Committee Decision

Prepared by: Werner Enderle, Stefan Wallner, Daniel Blonski (ESA), Joel Parker, Frank Bauer (NASA), Hui Yang, Xinuo Chang(CAST, China), Alexey Bolkunov (Roscosmos, Russia),

Date of Submission: 06/12/2017

Issue Title: GNSS SSV – Use of GNSS for exploration activities in cis-Lunar space and beyond

Background/Brief Description of the Issue:

During the WG-B GNSS SSV Working Group activities associated with the generation of the GNSS SSV Booklet, it became clear that the use of GNSS signals in support of missions within and beyond cis-Lunar space is possible and could contribute to improved on-board navigation capabilities.

Discussion/Analyses:

It is essential to understand the user needs for missions to cis-Lunar space and beyond, and to perform detailed analyses of the GNSS SSV capabilities and potential augmentations related to the support of missions to cis-Lunar space and beyond.

Recommendation of Committee Action:

WG-B will lead and Service providers, Space Agencies and Research Institutions are invited to contribute to investigations/developments related to use of the full potential of the GNSS SSV, also considering the support of exploration activities in cis-Lunar space and beyond.