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## **Report of the Working Group B: Enhancement of Global Navigation Satellite Systems (GNSS) Services Performance**

1. The Working Group on Enhancement of Global Navigation Satellite Systems (GNSS) Service Performance (WG-B) of the International Committee on GNSS (ICG) held in accordance with its work plan its eight annual meeting during ICG9 on 12 November 2014.

The WG-B Application Subgroup convened according to its Terms of Reference (ToR) for its fourth meeting on 22 October 2014 in Jeju, South Korea.

2. At the eight annual meeting of WG-B the following presentations were given and discussed:
  - (a) A briefing on the progress of the WG-B Application Subgroup and the outcomes of their fourth meeting is given by the co-chairs of the group. Trends arising from the monitored mass market user communities include among others service reliability, seamless navigation and high accuracy. Based on these findings the WG-B Application Subgroup will compile a report, targeting to quantify the performance needs per application domain in the next phase of work. The subgroup will continue to work according to its ToR and draw conclusions and recommendation to the ICG WG-B.
  - (b) The definition of an interoperable GNSS Space Service Volume (SSV) is an important area of work of WG-B. Continuing the work of prior WG-B sessions, the National Aeronautics and Space Administration (NASA) provides further background on the benefits an interoperable GNSS Space Service Volume will offer to all space users. Only the interoperable usage of multiple GNSS will allow for a sufficient number of ranging sources available for space users at high altitudes. The satellite antenna pattern profile is an important parameter for the SSV. Measured antenna patterns covering the main and side lobes for GPS II-R and II-R(M) spacecraft antennas are presented and are available on the GPS website. All service providers that did not yet submit their SSV characterisation, are asked to do so in order to follow up earlier WG-B recommendations.
  - (c) In continuation of the SSV discussion, the China Academy of Space Technology gives a presentation on the BeiDou Space Service Volume characteristics. The relevance of GNSS for space applications is confirmed. The SSV characteristics for BeiDou III Medium Earth Orbit (MEO) constellation and for combined MEO/Geostationary Orbit (GEO)/Inclined Geosynchronous Orbit (IGSO) constellation are provided. An extension of the SSV template is proposed.
  - (d) The presentation of Reshetnev Information Satellite Systems provides the GLONASS SSV characteristics based on the available template. The idea to improve GNSS capabilities for high orbit spacecraft navigation is introduced based on the transmission of navigation signals in opposite earth-direction.

- (e) The European Space Agency (ESA) presents the status of the Galileo SSV characterisation. The relevance of GNSS for space applications is underlined. The Galileo SSV characterisation is currently on-going following the conventions identified by ICG WG-B. The two first Galileo Full Operational Capability (FOC) satellites launched in August 2014 are facing an orbital anomaly, which however gives the unique opportunity to characterise the SSV-relevant antenna off-boresight range directly from ground. The in-orbit testing of these two satellites need to be awaited before Galileo SSV characteristics are published; the release of this information is expected for Spring 2015. Members of the group highlight the benefit that ranging sources from satellites in non-nominal orbits and potentially not part of the operational constellation can provide for a wide range of applications, including this space users.
- (f) The Technical University of Moscow focuses on improving the accuracy of GNSS services. The provision of precise orbit and clock correction parameters at high rate is an important element to improve the accuracy at position level based on Precise Point Positioning (PPP) methods. Also the usage of wide band signals allows for an important reduction of the multipath error.
- (g) The Institute of Space Device Engineering follows up WG-B recommendation 2 of ICG-8, reviewing the Time To First Fix (TTFF) Methodology. In order to establish consistently the TTFF, it is important to fix the initial condition including the GNSS receiver type, the start condition, the number of correlators and possible assistance channels. While the warm start condition is considered questionable due to a large quantity of possible starting conditions, the usefulness of the cold and hot start TTFF is confirmed. It is proposed to complement the TTFF methodology by a parameter characterising the Time to First Track (TTFT), that could be applied to pilot signals.
- (h) The Geodesy and Satellite Navigation Laboratory at the University of Trieste presents the latest results on the particular application of GNSS/Inertial Navigation Systems (INS) integration for the monitoring of cableways dynamics. Monitoring of the cabin's and cableway pillar's dynamics requires a very high level of accuracy and signal continuity in the particular environmental conditions. The integration of GNSS and INS sensors can fulfil the needs.
- (i) The benefits of a high number of GNSS ranging sources for Real Time Kinematic (RTK) applications is the subject of the presentation given by Topcon. In open sky environment test results show that RTK solutions based on two constellations are already good and that the addition of a third constellation does not provide further improvement. However, in challenging environments like urban canyons or tree shadowing, some dual constellation RTK results are unsatisfactory and triple constellation RTK can offer best results. The presented test results show the benefits of multi-constellation GNSS solutions.
- (j) The European Commission and the Federal Aviation Administration provide the latest update on Multi-Constellation Safety-of-Life (SoL)

Activities with particular focus on Advanced Receiver Autonomous Integrity Monitoring (ARAIM). The objective of ARAIM is to provide aviation users with vertical guidance (down to LPV-200) at global scale. An EU/U.S. working group elaborated two candidate architectures, the Offline (similar to RAIM) and the Online (similar to SBAS) ARAIM architecture. Differences between the Offline and the Online ARAIM architecture lie in the areas of trust in the core constellation, independent ground monitoring needs, content and update rate of the Integrity Support Message (ISM) required by the avionics. In relation to ARAIM a list of questions is existing that will be included in a report of the EU/U.S. ARAIM group together with a description of the ARAIM concepts. The report will be published at the relevant GPS and Galileo websites in the coming months.

- (k) The European Space Agency provides insight in the NeQuick model made use of in Galileo to correct the impact of the Ionosphere for single frequency users. The NeQuick model is recommended by ITU-R for the prediction of propagation effect and has been adapted in Galileo. A long term measurement campaign shows the improvement in terms of residual error when applying the Galileo NeQuick ionospheric corrections compared to other established ionospheric correction models. In equatorial regions the Galileo NeQuick correction capability shows considerable good performance compared to other models. A step by step description of the Galileo NeQuick model together with supportive material will be available to the public in the coming months.
- (l) The National Aeronautic and Space Administration introduces the existing Search and Rescue (SAR) concept and their implementation as dedicated additional payloads onboard GNSS satellites (MEOSAR) and associated ground infrastructure. Galileo and GLONASS already support MEOSAR and GPS will also host SAR repeaters on 24 GPS III satellites. While Galileo and GLONASS will support a SAR Return Link Service (RLS), the implementation of a SAR RLS in GPS is currently not in the concept of operations. The group recommends to conduct further coordination on SAR aspects through the existing COSPAS-SARSAT bodies.
- (m) Frequency jumps of the satellite onboard clocks are categorized as feared events as they will affect the accuracy directly. The Indian Space Research Organization presents their latest results on the detection and mitigation of frequency jumps for Rubidium Atomic Clocks leading to units with enhanced integrity. The applied principle bases on the monitoring of the main clock by two test clocks. Test results show the obtained improvements.
- (n) The rejection of interference is a research area gaining in relevance. The Moscow Design Bureau "Compas" focuses on the suppression of interference at antenna level by means of beamforming. Different concepts for the estimation of the Direction of Arrival are presented. Additional measures for interference mitigation to be applied at digital level are recommended. Based on these concept an anti-jam GPS/GLONASS receiver has been developed.

- (o) The Institute of Space Device Engineering presents their work on innovative approaches for GNSS antenna modules. Solutions for single and dual band and different form factors serving various application needs are identified.
  - (p) The Institute of Space Technology and Space Applications recognizes the interference and jamming threat for GNSS users and assesses mitigation concepts. In addition also spoofing attacks by GNSS-repeaters is an emerging concern for GNSS application developers and GNSS users. The exploitation of polarization differences between the authentic GNSS signals and a jamming device is an additional possibility that can be exploited for interference/jamming mitigation. The developed concept bases on the assumption that the jammer emits a linearly polarized signal. Promising test results are obtained based on the polarization method when compared to interference mitigation concepts applied at digital signal processing level.
3. WG-B members were invited to propose recommendations enabling the enhancement of GNSS service performance. The status of previous WG-B recommendations was considered. Two recommendations were presented and adopted by the ICG Plenary. The endorsed recommendations of WG-B at ICG9 are listed in Attachment 1.1 and 1.2 of this report.

**ATTACHMENT 1.1****WG-B Recommendation 1 Endorsed by Committee Decision****Prepared by: WG-B****Date of Submission: 13 November 2014****Issue Title: Nequick Ionospheric Model****Background/Brief Description of the Issue:**

Ranging errors induced by ionospheric effects constitute one of the largest error source for a single frequency GNSS user. Ionospheric models are capable to estimate the ionospheric impact on the ranging measurement and compensate for it. Good ionospheric models are important to enhance the ranging accuracy for single frequency GNSS users.

**Discussion/Analyses:**

Results obtained applying the Nequick ionospheric model implemented in Galileo indicates good ionospheric error compensation capability. WG-B members showed interest in this model and encouraged to gain further insight regarding the implementation of the Galileo Nequick model at receiver level such as to allow for comparisons wrt. alternative ionospheric compensation models.

**Recommendation of Committee Action:**

- *To distribute to the Service Providers and Users the document providing the detailed description of the Nequick algorithm implemented in Galileo for the correction of the ionospheric error in single frequency users;*
- *For the Service Providers and interested users participating in the ICG, to assess the performance and usability of a Nequick ionospheric correction algorithm for the single frequency users similar to the one adopted by Galileo in view of its expected good performance compared with other models, i.e. at low latitudes.*

**ATTACHMENT 1.2****WG-B Recommendation 2 Endorsed by Committee Decision****Prepared by: WG-B****Date of Submission: 13 November 2014****Issue Title: Interoperable GNSS Space Service Volume (SSV) Characterization Outreach****Background/Brief Description of the Issue:**

WG-B has followed in the last period the Recommendation to establish an “Interoperable GNSS Space Service Volume”. WG-B has addressed this topic at technical level at several Meetings and has identified the advantages of an Interoperable GNSS SSV for the Space User community. So far several GNSS service providers supported this initiative either providing already their SSV characterization or indicating their intention to do so in the near future.

**Discussion/Analyses:**

In order to communicate to the public domain the advantages of an interoperable GNSS SSV and the relevant support of every GNSS service provider, interested members of WG-B have agreed to elaborate a booklet identifying the advantages of an interoperable GNSS SSV for space users

- The support of every GNSS service provider to an interoperable GNSS SSV based on an
- agreed comprehensive template
- An estimation of the capabilities of the identified interoperable GNSS SSV, given the individual SSV characteristics per service provider as input

This booklet is considered of particular interest for GNSS space-receiver manufacturers. The booklet is meant to characterize the contribution of the different GNSS to an interoperable GNSS SSV for the benefit of the users, but shall not induce commitments as they are handled by the individual GNSS Providers in their respective Performance Commitment Documents.

The booklet shall be worked out by WG-B members representing GPS, GLONASS, BeiDou, Galileo, QZSS, IRNSS and they shall organize the necessary work to have a version for final commenting and approval within WG-B at ICG10 ready.

**Recommendation of Committee Action:**

*GNSS Providers are recommended to support the SSV outreach by making the booklet on “Interoperable GNSS Space Service Volume” available to the public through their relevant websites once the booklet is available.*