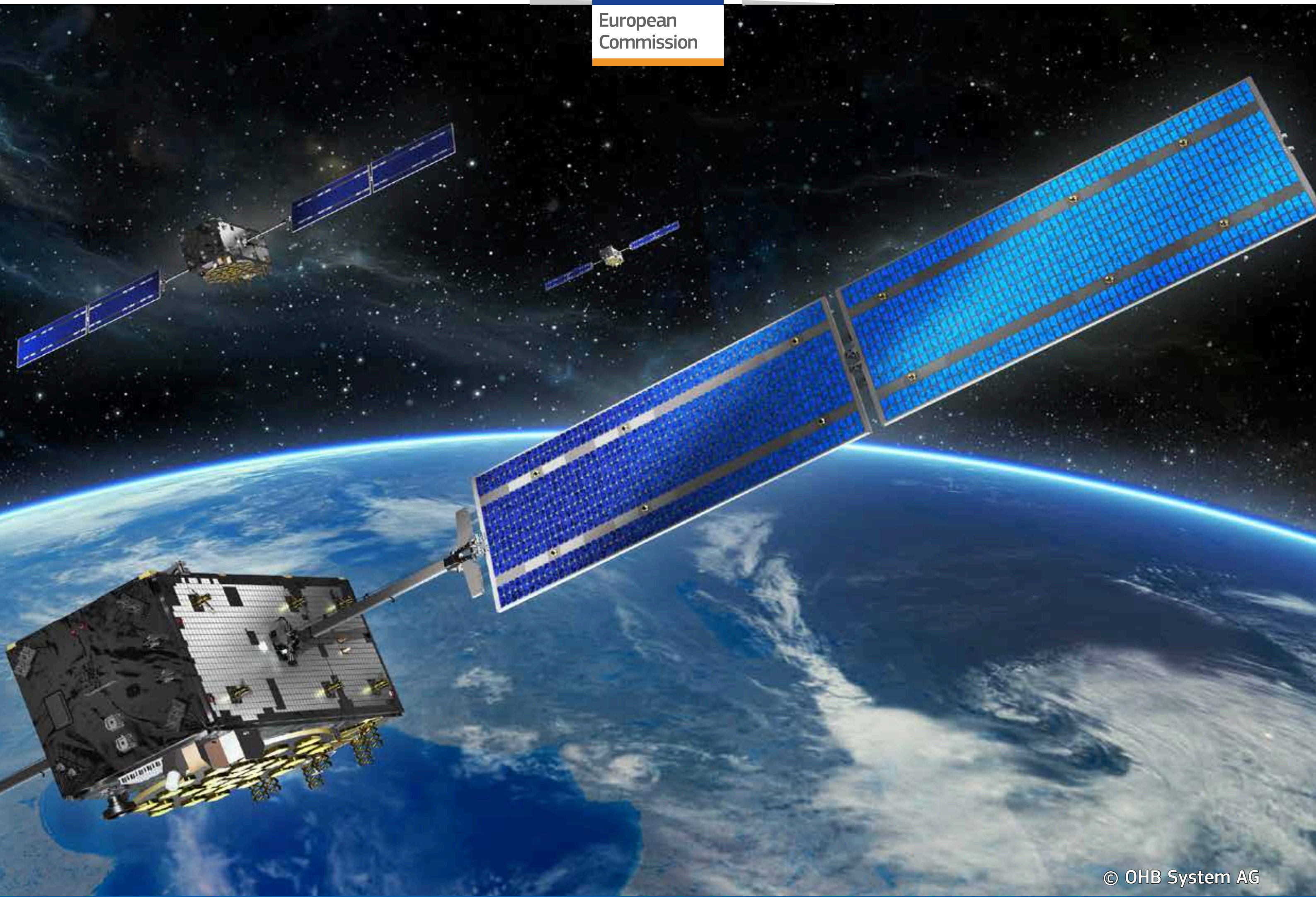

Horizon 2020 Stakeholder Consultation Workshop Report

Navigation Satellite Research and Technology

4th June 2014, Brussels

Enterprise and Industry

Contents

Executive Summary

The stakeholder consultation workshop on satellite navigation research and technology development under H2020 was very well attended by about 150 representatives from space industry, including SMEs, technology institutes, and academic researchers. This was the first open consultation workshop held in this field. An important rationale to organise the consultation workshop at this particular time is that from 2015 onwards GNSS (Global Navigation Satellite Systems) R&D (research and technology development) will be funded under Horizon 2020 EU programme. In the course of 2015 there will be a transition between the currently operational EGEP (*European GNSS Evolution Programme*) and Horizon 2020.

The objective of the workshop was to bring together the various GNSS R&D stakeholders, and to:

- inform stakeholders on the ongoing processes to define the evolution of Galileo and EGNOS (European Geostationary Navigation Overlay Service) systems, the planning of R&D activities in that framework, and the respective roles of the Commission, ESA, and GSA in the implementation of the R&D programmes;
- consult stakeholders during the six topical sessions on their ideas, concerns and capabilities for GNSS research and development.

During the plenary session representatives from the Commission provided information about the planning and ongoing processes taking place on GNSS evolution and R&D. It was explained that this workshop did not cover receiver R&D, because that will be funded under the GNSS Programme, the so-called 'fundamental elements'. A separate R&D consultation event will be organised in the fall of 2014.

The information session was followed by presentations by representatives of industry, SMEs, and academic institutes providing an overview of the different perspectives. The general conclusions were that in order for the EU to evolve and maintain top-level satellite navigation systems, such as Galileo and EGNOS, research and technology development needs to be strengthened. Although a strong space industrial base in Europe is key to satellite navigation capabilities, the active role of research institutes and SMEs is equally important and should be fostered through the Horizon 2020 R&D programme. The importance of the coordination of the R&D actions on receivers, in the frame of the overall GNSS R&D programme was also emphasized, noting that receiver R&D was not part of the workshop.

During the six topical sessions the subjects were introduced by 4 – 6 speakers covering different aspects and points of view. This was combined with extensive discussion sessions during which ideas and inputs from all participants to the sessions were solicited. This resulted in all cases in lively and in-depth discussions, providing a wealth of information relevant to the design of the different parts of the GNSS R&D programme. Those inputs will be used for the long term planning (2015 – 2020) of Horizon 2020 by the Commission, GSA, and ESA.

The session on Galileo space infrastructures R&D discussed technology and system developments that could contribute to the next generation Galileo constellation, to be launched starting from 2023. New technologies (e.g. for payload, propulsion) or concepts (e.g. alternative orbits, replenishment strategy) were discussed in particular for their potential to provide enhanced performance, robustness and/or cost savings.

The session on Services and Mission R&D focussed on the potential for new services (e.g. timing service) and innovative use of already planned services (e.g. monitoring of PRS and search and rescue return link). Better service performance, especially in challenging environments such as urban areas and high latitude areas – in the case of EGNOS – can potentially be achieved by alternative orbits (IGSO) and by R&D in ionosphere and troposphere leading to better monitoring, modelling and dissemination of corrections. The potential to exploit synergies between EGNOS and Galileo was as well treated (e.g. for operations).

Signals R&D is a key area that literally links the space segment to the ground segment. There was a strong recommendation to better integrate the R&D communities to avoid disconnected developments at either end. In signal evolution a highly complex trade-off needs to be made between different elements such as robustness, integrity, and security requirements. Synergy between satellite navigation signals R&D and other signal processing domains (e.g. image processing, big data) should be better explored because this is demonstrably leading to cross-fertilization and new ideas.

EGNOS is an operational system and therefore changes in the EGNOS system are more complex to implement. An important part of the discussion focussed on the possibilities for a better performance of EGNOS by using Galileo in addition to GPS, and possibilities of a greater non-dependence by developing Galileo only services of EGNOS. The extension of services and improvement of performance in the Nordic and eastern regions could possibly be achieved by using non-GEO satellites, possibly Galileo satellites, for EGNOS broadcasts.

The discussions in the session on Galileo ground infrastructure and operations clearly straddled the boundary between R&D and lessons learnt from current operational experience. However, it is important to identify the R&D needs precisely in this domain, because this is a high-cost element of the Galileo system where innovative approaches may make a marked difference in the overall performance, security and cost reductions of the system. Pre-operational testing is considered to be an important component of the R&D cycle before implementation of new concepts and technologies into the operational system.

The final session addressed key topics on scientific applications of GNSS, for example precise geodetic measurements, or atmosphere and ionosphere research, as well as basic research in technologies relevant to GNSS, such as for example atomic clocks. The GNSS basic technologies and scientific research community is potentially undervalued in the EU compared to the US, but is essential to ensure that ground-breaking new ideas form and develop into cutting-edge technology and applications in the GNSS domain.

A number of topics of cross-cutting importance were discussed in several sessions. To increase the robustness of the Galileo system and to decrease the dependence on non-EU manufacturers it was recommended to invest in R&D in the so-called ‘critical technologies’. In several sessions a more synergistic approach was advocated, for example between Galileo and EGNOS, between different GNSS systems, and between satellite navigation and Earth observation. Common building blocks may be identified, which could be tackled with a more modular approach. Finally, as in other domain of space R&D, there is a need to test new technologies and concepts by in-space demonstration projects.

SECTION 1

Introduction

Horizon 2020 covers all research and innovation activities at EU level. This includes under the Space section the research and technology development actions related to EU GNSS. As done in 2013 for the overall H2020 Space part, the EC organised this specific workshop on satellite navigation, with six different topical sessions. The purpose of this workshop was to directly consult the EGNSS research and technology development community, so as to gather their input on the implementation of the H2020 actions related GNSS, to be implemented by the EC, GSA, or ESA.

In a first step of the registration process an invitation to express interest to participate in the workshop was sent in April 2014 to Member States, National contact points and a wide range of EU GNSS stakeholders. The procedure to register included a questionnaire to collect the inputs provided by each participant to the topical sessions of their interest. On the basis of this registration, potential speakers were selected to provide presentations in each topical session. In total about 150 persons attended the workshop, which took place on June 4th, 2014. The topical sessions were co-chaired by EC, JRC and GSA (see Agenda in Annex B).

SECTION 2

Plenary Session

During the introductory session several presentations were provided to set the scene for the workshop from different perspectives. Those presentations are available on

http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_id=7440

The first presentation by Hermann Ebner (EC) covered the overall framework for the definition of the Galileo and EGNOS evolution, explaining the overall top-down approach where the mission and system evolutions are driven by the user needs and aimed at maximizing the cost-benefit ratio.

The context of H2020 and the transition from the EGEP to H2020 was presented by Tanja Zegers (EC).

In the subsequent three presentations the GNSS related R&D was analysed from different perspectives: academic, SME's, and space manufacturing industry.

Professor Günther (Technical University of Munich) started by discussing several areas of research where Universities could have an important role, for example to increase the robustness, time keeping and positioning accuracy of GNSS systems. He made the point that in an academic context the research topic must be truly innovative, of high quality, and it must be publishable. This last point is often a problem in current GNSS R&D projects, and this has been limiting the European academic contributions to EGNSS R&D. It is also essential that information about the GNSS system is openly available to academic researchers. Surprisingly, this has been more the case for GPS than for the EU systems EGNOS and Galileo. Professor Günther made a strong case for more academic involvement in EU GNSS R&D projects. Academics are used to achieve good results in under formulated problems and the science community is a very demanding user, pushing the systems to the limits and thereby achieving new concepts and innovative technologies.

Mark Dumville (Nottingham Scientific Limited) started by explaining that the GNSS world will change considerably in the next years. There will be new constellations, new signals, Japan are developing innovative ways to use GNSS and India will start using S-band for GNSS. Therefore there is a need in the EU to expand the innovation space in the field of GNSS, with more blue sky thinking. Innovations, where SMEs can play a considerable role, will also lead to cost-reductions on the medium and long term.

SME could have an important role in the test segment, for example in GNSS receivers. Mark Dumville indicated that it was an unfortunate decision to exclude receiver R&D from this workshop. In receiver R&D there are two distinct segments: 1) the mass market receivers, and 2) the receivers for the ground segment infrastructure. Both are connected to the GNSS system and receiver R&D is best treated as a package together with other GNSS R&D topics.

Pierre Lionnet (Eurospace) presented the results of a consultation that Eurospace conducted with the space manufacturing industry. He started by making a similar point as the previous speaker on receivers: an important segment of receiver technologies is actually part of the system and should not be treated separately.

For both Galileo and EGNOS he provided the main outcomes of the consultation in terms of R&D topics that would be relevant for the upcoming years, indicating that the main overall challenges will be to achieve synergies between Galileo and EGNOS and between different constellation, multifrequencies and the increasing number of signals, security aspects and time keeping (atomic clocks). The goal should be to increase the performance to cost ratio by more advanced satellite platforms and innovative concepts such as electrical propulsion systems. The report on the in-house consultation will be provided to the European Commission and ESA in 2014.

SECTION 3

Topical Sessions

3.1 Session 1: Galileo Space Infrastructures R&D

The Galileo space infrastructure R&D session was co-chaired by Eric Guyader and Xavier Maufroid (EC), the rapporteur was Andreia Hanomolo (EC). The session focussed on research and technology development opportunities for the evolution of the space component of the EGNSS infrastructure. This included access to space and propulsion, the use of alternative orbits, the size and functionality of the platform, the inclusion of additional payloads and implementation of new functions, the test and validation of new capacities, and in general the evolution of the systems and sub-systems as well as the supply chain of specific high-end components.

Six speakers were invited to present their views, and a round of questions with the audience followed.

The development of several global satellite navigation systems poses some evident constraints to the evolution of Galileo. With four global constellations and more than 100 satellites in MEO orbits, the end-user is faced with an over-supplied multi constellation context that will push him to select the best two constellations for his navigation purposes. This competitive situation forces Galileo to provide added-value with respect to the other GNSS, in other words to be superior both in terms of service portfolio and in terms of performance. In addition, with so many satellites operating alongside, interference protection must be reinforced. One approach was proposed to consider only one global system made of several independent contributions by countries or regions, where each provider would operate a reduced number of satellites. However, this is not compatible with the political and strategic requirement for the EU to provide independent services on a global scale.

In order to best meet the user needs, a regional segment operating alongside the global component and featuring a service improvement over Europe offers interesting perspectives. Such a hybrid system would allow serving users with enhanced performance and also to differentiate the service portfolio between global and regional use cases. This approach is particularly relevant for users located in cities and urban canyons, and has the potential to create synergies between GNSS and SBAS.

Cost optimization was seen as a key trend, and several alternatives were proposed. It is commonly agreed that the system shall remain simple to operate, and that complexity shall be avoided. The ground-segment was identified as an area where cost-saving could be made by developing innovative elements in the space segment resulting in a reduction of the ground segment and an increase of the overall system robustness. Strategies for cost reduction and easier operations include accommodating more satellites on a given launcher, or reducing the large number of ground stations; orbit types are an important parameter in this picture. In this respect, a LEO constellation was proposed as an alternative to the complex MEO orbit, allowing the use of a higher number of spacecraft much simpler in their conception, but at the expense of a higher load on the ground segment and of a higher risk at launch phase.

In addition, several speakers stressed the importance of a smart satellite modernisation and replenishment strategy. Replacement of a global MEO constellation can take very long time, up to 15 years in the case of GPS for example, with sometimes a long delay before a critical number of satellites in orbit is available; a more flexible orbit would allow an immediate availability of the next generation advantage(s).

ISL was widely addressed. Many benefits can be drawn from the use of such payload, but the technology is not mature yet and technical hurdles prevent today the development of operational systems for satellite navigation missions. The situation is that it requires high-end components (such as high speed electronic components) that are currently not available in EU (critical technologies) due to the high investment costs in comparison to the relatively small size of the market. However, it was commonly agreed that sooner or later the technology will attain a sufficient readiness level, and could become desirable equipment for many space missions. In this respect, it was recommended that EU engages in the development of such equipment to be able to supply it at mid to long term, reducing at the same time its technological dependence. Eventually, it was recalled that the integration of ISL is not inconsequential, and has the potential to affect deeply the current mission concept; in this sense ISL should be analysed not only from the space segment point of view but should take into account a total vision of the satellite navigation mission (architecture and system concepts, assessment of potential alternatives, availability of electronic components, robustness and reliability of the approach, replenishment strategy, backups…).

Propulsion was also seen as a potential area for evolution. Current discussions contrast chemical and electrical approaches, and trade-offs include cost of launch, radiation environment, load on the ground segment, complexity and mass of the platform, and rapidity of injection into orbit, the latter criterion being particularly relevant when it comes to replacing a spacecraft by a ground spare. For the decommissioning phase, it was proposed to embark a separate thruster independent from the platform, which would be used to transfer the spacecraft into graveyard orbit. This approach would allow using the propellant up to exhaustion before the decommissioning device takes over for de-orbiting manoeuvres. This approach would allow a direct increase of the lifetime of the satellite in orbit.

In terms of new services having a direct impact on the space segment, the extension of the service volume to space users was mentioned, in particular for users located above the MEO constellation (GEOs) and beyond (mission to Moon). An alert broadcast service was also proposed, making use of a steerable antenna to serve a given community at risk; it was even proposed to have the users contribute to the alert service (bi-directional service) by allowing them to upload observables into the system in order to feed it with local measurement. Although such a cloud-like approach could be extended to other purposes (typically ionosphere and interference monitoring), it raises questions on the validity and integrity of the observables, and would not fit with the current system security requirements. In addition, secondary payloads and partner-missions can be seen as a risk for the core navigation function, by imposing design drivers and interdependencies with many additional actors.

At the level of systems and sub-systems, innovative ideas were proposed in fields such as atomic clocks (optically pumped, mini PHM), solid state amplifiers, wireless sensors in replacement of conventional wired solutions (gain space and mass on the platform). In particular, the provision of early flight opportunity was requested to be able to test and validate in-orbit innovative payloads. It was also recommended to rationalize the equipment at platform level, by exploiting synergies with other equipment and thus avoiding unnecessary duplication of functions.

In general, it was recommended to support the development of space-qualified electronic component (high speed digital modulation, AD/DA converters…) in order to ensure technological independence of EU, to optimize the different source of funding and to exploit the findings of general technology programs that could benefit to a satellite navigation mission also.

3.2 Session 2: EGNSS Mission and Services R&D

The EGNSS Mission and Services R&D session was co-chaired by Juan-Pablo Boyero (EC) and Alberto Mozo (GSA), the rapporteur was Thibaut Miquel (EC). The session focused on research and development ideas for the evolution of the Mission and improvement of the Services to be provided by future EGNOS and Galileo Systems. Research and development activities are necessary to ensure the delivery of efficient user-oriented and cost-efficient services in the next generation of EGNSS. A large range and quality of the services provided is indeed expected to be a differentiator for Galileo in the context of the competitive market of GNSS constellations.

Six speakers were invited to present the ideas that they had submitted to the Workshop as a way to launch the discussions. After the short presentations, the audience immediately engaged in discussions over a variety of topics.

Several interventions advocated research activities to foster the Galileo Time infrastructure and the potential benefits of establishing a stand-alone Timing Service. A large set of users rely currently on GNSS time (GPS) to synchronize complex system in the fields of energy distribution, finance, transport, telecommunications networks and science. Beyond its current use, future applications such as velocity control on motorway can be foreseen. The needs are focused on better performance in terms of continuity, reliability of service or authentication. Interest in higher timing accuracy comes from specific scientific fields: deep space missions, radio-astronomy, and quantum cryptography and calibration laboratories. For the majority of users, current timing performance (stability or synchronization) is sufficient and the concerns are mainly related to the reliability and continuity of the timing products. It is recognized that the timing capabilities are already provided as part of the Galileo OS and PRS, but a stand-alone service would better respond to the above mentioned needs. Possibilities for regulation (to promote the adoption of Galileo time as standard within Europe) and certification around this new service were also raised by the participants.

The potential benefits of inclined geosynchronous and geostationary satellites were presented. Besides achieving better performances for the current services in urban environments, IGSO satellite also allow for disseminating correction data for users at high latitudes, extending the EGNOS coverage areas in eastern and northern part of Europe, collecting observables for ionospheric corrections from a wider area, and providing for additional communication capabilities (e.g. alerts). Research activities are proposed to analyse the best way to compensate for the signal space losses as a result of the use of higher altitude orbits. This can be achieved either at space segment level through the improvement of navigation antennas or an increase of their EIRP or at user segment level through the improvement of the user antenna, the coding/decoding schemes or the code tracking algorithm.

High accuracy was discussed as part of the discussions on tropospheric corrections. The current accuracy of the SBAS troposphere correction could be significantly improved with near real-time or real-time precise troposphere delay corrections models. The capability for generating and disseminating those corrections through the GNSS signals can be developed in Europe. This would also ensure the independence of the high accuracy service, which is relevant for the currently foreseen CS. The introduction of the CS was much appreciated by the participants in general, with some positive remarks on the continuation of the currently ongoing development of a CS Demonstrator.

Several ideas were proposed related to the PRS. On one hand, the proposal for development of a PRS monitoring capability was widely welcomed. The question is open whether this capability would be part of the System or external to it. The idea of monitoring is also applicable to the rest of services, addressing capabilities such as detection of spoofing and eventually tracking down the origin of the attack. On the other hand, a PRS-based GBAS for automated take-off and landing for RPAS was proposed, which would be the equivalent of the EGNOS LPV service used by commercial aviation. Another high performance service for the PRS would be the provision of assistance data in real time in order to improve availability and robustness of current PRS.

With respect to Search and Rescue, several participants highlighted the contribution that Galileo is making to the international Service, coordinated by COSPAS-SARSAT. Potential areas for evolution were identified for the SAR Link, for which Galileo is in a leading position. In this respect, R&D for next generation beacons and MEOLUT stations fostering the introduction of the RLS were proposed.

Finally, the potential to exploit synergies between EGNOS and Galileo was indicated, in particular regarding their operations. The need to develop related Key Performance Indicators for Operations as well as to ensure smooth transition of operations between different generations of systems was presented. Highlighting the successful use of EGNOS by the aviation sector, several participants brought up the point of the development of services for both rail and maritime sectors in the next generation (EGNOS V3). Standardization of the services for those sectors is needed in parallel. A proposal was also made to consider Galileo-only Services for EGNOS V3, as the plans include GPS only (current service) and Galileo plus GPS. Related to it came the question whether regulating the use of EGNOS for civil Aviation in Europe should be considered, in a similar way as other Regions of the world are regulating the use of their national Systems.

3.3 Session 3: GNSS Signals R&D

The session was chaired by Matteo Paonni (JRC), the rapporteur was Eva Boethius (EC). It focussed on R&D leading to potential enhancements of the navigation signals transmitted by the GNSS systems. This included more efficient modulation and multiplexing schemes, advanced error correction techniques, navigation message design improvement, as well as authentication mechanisms provided both at signal and at navigation message level.

The discussions in the session made evident how most of the Galileo Mission Evolution directions are dependent on the signals and their possible evolution.

Starting from the fundamental cornerstone represented by the backward compatibility, those elements translate into some possible GNSS signals R&D high level requirements such as; signals performance improvement, evolution towards better compatibility and (possibly) improved interoperability with other GNSSs, increased robustness and security.

The panellists provided the view of industry, SMEs and universities on the main potential R&D areas:

1) New and evolved modulation and multiplexing techniques, to allow the (more efficient, possible, eventual) introduction of new optimized signals;
2) Advanced forward error correction techniques, to improve the navigation message robustness;
3) Signal authentication, as a mean to improve security and robustness against threats like spoofing;
4) GNSS signals optimization criteria, being very valuable in general in order to be able to identify the various aspects which are part of this complex matter.

Furthermore, some elements of general value to be considered emerged:

1) Need to have a closer integration and communication between the different R&D communities dealing with different but strictly related aspects (signals R&D either with receiver/signals processing R&D or with terrestrial positioning R&D communities are two examples);
2) When looking at evolution of signals it is necessary to look at the overall picture (including downstream applications and receiver design);
3) Signals design and their optimization are the result of a very complex trade-off exercise (multidisciplinary and multidimensional);
4) Payload design and the associated budget is one of the most constraining elements to be considered;

5) Need to consider the user needs and the evolving technology. Receivers, infrastructure and applications have to be dealt with in a holistic coherent way to comply with the needs of the user community.

During the session it was also stressed that there are R&D gaps to overcome. In particular it was stressed by the panellists how considering in a closer look the contribution from different R&D communities would contribute to drive innovation, i.e. signal design and receiver/signal processing R&D, or GNSS and terrestrial positioning/communication.

As a general conclusion the following could apply: new features and completely new approaches could be considered, in order to adapt to new emerging needs and risks, provided that those are supported by a real user demand and always considering backward compatibility as a fundamental requirement. Also, these R&D needs should be analysed in a close loop considering the continuous feedback from user applications and receiver design and development.

3.4 Session 4: EGNOS Research and Development

The session was chaired by Ignacio Alcantarilla (EC), the rapporteur was Eva Boethius (EC). It focussed on R&D for new or improved EGNOS Services, Mission or Infrastructure. This included new services to enable new markets, new or improved Infrastructure, improved HW and SW techniques more robust to obsolescence, improved system architecture and synergies between EGNOS and Galileo.

From the aviation perspective the need for interdisciplinary R&D and the need for continuous simple and robust interoperability were expressed. For the moment the life-cycle cost cycle is rather slow and expensive. It is important to avoid R&D duplication with SESAR2020 Research and Innovation Programme. For ARAIM it was stressed that its requirements should be kept reasonable and to limit the need for complex data links. Also the issue of how to build confidence and authorization was discussed.

It was stressed the need to link the R&D activities to the end-user and the exploitation of services, since EGNOS and GNSS in general are part of a wider picture including other constellations, other navigation aids, etc. He also raised the potential R&D need for the study of software upgradable receivers to adapt to fast change pace needs from different sectors as well as the possibility to integrate SBAS and ARAIM in more advanced platforms. In any case, ARAIM services will in any case not be implemented before the 2030 timeframe and then it should not impact the existence of an EGNOS V2 around the 2020 timeframe.

The possibility to share infrastructure between EGNOS and Galileo was discussed and the Russian case of sharing of GBAS and SBAS stations was mentioned as an interesting example. An important aspect to consider in the case of sharing is the different level of HW/SW development between EGNOS and Galileo, with the former with more critical development standards to ensure the SOL service than the latter.

In terms of services, several ideas were discussed such as the possibility of using the available bandwidth to provide through the OS an Emergency message (in line of the ALIVE concept studied in the past). This seems to be a promising idea. Also, it was mentioned that the current EGNOS System was not driven by the OS but rather by the SOL service and then it was believed that a design targeted also for OS users could improve its performances (for instance with dedicated signals). An idea on the possibility to use the EGNOS Data Access Service (EDAS) as a service to forecast the service levels of EGNOS was also discussed.

The need to perform R&D activities to improve also the current algorithms in EGNOS was raised. Some messages were given that the current EGNOS V3 developments will not significantly improve such algorithms and that further R&D activities may be needed.

Also, the idea that already EGNOS could be delivering additional activities without major re-design was introduced and the upcoming LPV-200 service level was mentioned as example.

Further needs on research on EGNOS SIS Authentication (integrity aspects and cost/benefit) were raised, also in relation to Galileo authentication, and potential future augmentation in the Arctic region.

The Artic regions constitute an area of interest for potential future R&D in terms of impact/market analyses, international cooperation, and new use of EGNOS/Galileo services. The ongoing project on GNSS & SBAS Applications (Artic Test bed) has so far been promising for High Integrity services. There would however be a need further define coverage, constellations, cost/benefit and business cases.

One of the major challenges in the Arctic for SBAS systems is the broadcast means since geostationary satellites do not cover Arctic regions (76 degrees North is the limit of visibility with 5 degrees elevation).

Overall, it was a well-attended and very lively and interactive session concluding that there is further need for EGNOS R&D, in particular to identify the highest potential use of EGNOS v3, in terms of new services and improvements of algorithms. The potential use of EGNOS stored data to validate the system and to build further research on was also discussed.

International cooperation and research on EGNOS broadcast through non-EU signals also needs further exploration.

3.5 Session 5: Galileo Ground infrastructure and Operations R&D

This session was co-chaired by Pascale Flagel (EC) and Horst Faas (GSA), the rapporteur was Antonio Rolla (EC). Cost-effectiveness of the ground segment is one of the important drivers for the evolution of Galileo. Next generations of the Galileo Control and Mission Segment have to be developed with great attention to maintenance and operations costs. New ideas and research and development leading to innovative solutions in this field are needed, especially in the frame of a ground segment which has to obtain and to maintain a security accreditation.

Since the operations represents a big share in the overall cost of the Galileo system, there are potential axis for cost savings that can be explored. With this objective, the panellists discussed ideas for optimization and evolutions of the operations. In general it was seen as important to better integrate Ground and Space Segments development with the operation requirements from early R&D, design and specification phase. This will lead to a streamlined operations organization, to simplified interfaces, and a program planning and evolution taking into account operational needs from the onset.

The role of security in the GNSS systems and the impacts of new potential threats have been presented. Several potential areas of R&D to increase security and to reduce the cost have been presented but it is recognised that the security domain goes much beyond the GNSS world and involves several other domains of activities.

Several areas of considerations for potential research to reach the objective of cost reduction and increase of security have been identified (Cryptographic services and key management, Strong authentication, Cyber security and network defence, Safety and Security Accreditation, Navigation Data Integrity and Authentication, Improving Physical Security, GNSS Monitoring and Sensor Stations)

In the specific case of Galileo, the panellists highlighted the fact that the system definition suffered from late introduction of the security requirements. A recommendation for next generation is to introduce security earlier in the system design.

The importance of taking into account the maintainability and operability in the next generations of Galileo ground segments was highlighted. The identified drivers for the new ideas and research for the Galileo system are the security, the operability, scalability and service continuity. Proposed R&D ideas include: reorganize operations with a centralized approach, with an alarm based M&C, virtualization, improved troubleshooting; automation to increase robustness to human error; segregation of duties and event correlation to avoid interference and improve security; the use of technology evolutions already available such as smartphones, tablets; distributed operation concepts, operator-adaptive MMI.

The lessons learnt from EGNOS have suggested optimizing the life-cycle with a full incremental approach, taking into account the operational requirements in early stage and with increased test means.

The trends for the ground systems evolutions related to scalability, technology evolutions obsolescence, and increasing security threat level were presented. G2G may have an important impact on the ground segment, depending on the choices to be made (i.e. inter-satellite link, electric propulsion, etc). A range of potential adaptations may be studied in the field of automation, merging of GCS/GMS, more modular architecture, virtualization and simulation environment techniques, next generation crypto technology, update of threat models, TTC resilience measures, and various software changes.

The final presentation discussed major lines for research and development. The first point is that the ground infrastructure and architecture can be simplified thanks to the SOL. The use of COTS with a robust product history should be investigated, but taking into account the potential IPR issues. The use of technologies and approaches of satellite Telecom market can be investigated (virtualization, open architecture and standardization, MMI simplification, automation). Finally, shadow system to deploy new versions and advanced integration test benches could be employed to integrate new technologies.

The following main conclusions can be derived from the discussions of the panel.

1) In order to tackle the issue of operating in a seamless way a system which is under evolution and under deployment, it is suggested to introduce in H2020 work-plan activities to investigate the potential optimisation of the life-cycle. Fine synchronisation with the operational needs and a stepwise approach taking into account the operators improvements at each step might bring significant efficiency and cost savings. This might include improvements on the testing phases (test benches in real system scale or with improved automation) or on the deployment phase (optimized configuration control systems to better manage scalability and upgrades of the system).

2) In order to develop a system that is operable and not to operate a system as is it developed, it is recommended that the operability concerns are taken into account as soon as the system specification and design phase, i.e. well before the development phase and closely followed throughout the development phase and deployment phase. To tackle this problem in the existing systems the panel has issued a general recommendation to implement stepwise approaches to take into account the operator's constraints in the upgrade and versioning of the systems (this can be mentioned as part of life-cycle optimization studies at point 1).

3) A general recommendation is agreed by the audience to involve operations and ground segments on the R&D studies on all the domains (space segment, systems, signals…) that can have an impact on operations and ground segment. (i.e. ISL research should have also the involvement of operations and ground segment experts to provide a more global viewpoint). This recommendation has to be taken into account in H2020 work-plan whenever applicable.

4) The participants agree that significant improvements can be obtained in the domain of software architecture design and development

(virtualization, reuse of COTS with strong product history, modularity for evolutions and obsolescence management, frameworks where algorithms can be easily changed…) and operability (automation, centralized alarm, adaptive MMI). IPR and open source issues have to be carefully taken into considerations as well as security implications deriving from the use of COTS. An investigation could be made on how to apply RAMS philosophy to software products in order to anticipate and keep control of the impact of software failures on the system and final mission performance. It is strongly recommended to develop R&D axis to address this need in H2020 work-plan.

5) It has been highlighted that the security aspects are not specific to GNSS domain therefore research in this domain shall be coordinated. Several potential fields of improvements have been identified (see presentations points above) and the need of introducing the security requirements from the early stage of the project has been identified as a major cost reduction factor. It is strongly recommended to take into account the security improvements in H2020 work-plan.

6) The participants have identified the need to undertake system architecture feasibility studies with the objective to simplify the existing architecture that might have a strong impact on ground segment. SOL withdrawal has a not well analysed impact on Galileo architecture but also new potential system or mission level ideas can lead to new architectures (i.e. different message uplink rate). It is recommended to take into account these improvements in H2020 work-plan.

7) The participants have highlighted the similarities with different domains (non GNSS or non-space related) bringing examples of efficient solutions (in terms of software engineering, security, operations….). It is recommended to promote in the frame of H2020 work-plan a study on the state of the art and applicability of technological solutions from different domains to the GNSS world (Telecom, advanced software application systems….).

8) The involvement of a larger community (SMEs developing software at N-2 or below) as part of the high level R&D projects (system and architecture) has been pointed out as beneficial for the comprehensive result of the research. It is recommended therefore to take this constraint into account while formulating the H2020 work-plan.

It is reminded that the recommendations above are applicable to both Galileo and EGNOS and not strictly limited to the ground segments presented by the panellists (GMS, GCS) but have to be applied with a wider scope whenever dealing with ground segment and operations (i.e. in case of SAR).

3.6 Session 6: GNSS Science and Basic Technology Development

This session was chaired by Joachim Fortuny Guasch (JRC), the rapporteur was Andreia Hanomolo (EC). It addressed key topics on scientific GNSS applications and basic GNSS technology development. This included precise geodetic metrology, precise orbit determination, benefits of inter-satellite and inter-orbit links, satellite and chip scale atomic clocks, monitoring and forecasting of ionospheric delays and disturbances (e.g. scintillation), inferring of tropospheric delay products for precise GNSS positioning, GNSS radio occultation and GNSS reflectometry science.

The session started with a brief introductory speech by the five panellists. This was very useful to focus the open discussion with all the attendees of the session. The key topics and issues that were suggested for the forthcoming H2020 calls on the GNSS Programmes evolution can be summarized as follows:

1) Today's precise geodetic applications are based on multi-frequency multi-constellation GNSS technology. It is widely agreed that there is a significant margin for improvement of the precision of current geodetic products provided future R&D efforts could be focused on the following topics:

- Development of better estimation of inter-system biases between different constellations possibly leading to products broadcast to geodetic and high-precision GNSS receivers
- Devise algorithms to select the optimal set of observables to achieve the highest possible accuracy in the geodetic and high-precision products in a heterogeneous satellite, signal, and equipment environment
- Investigate the multi-purpose use of inter-satellite links, respectively, for time transfer, communications and ranging, which shall significantly improve the estimation of the satellite orbits. This unique capability in future Galileo's space vehicles would provide:
    - On-board determination of precise orbits and synchronization of satellite clocks to make a single constellation clock available to users.
    - Precise gravity field determination with high temporal resolution.
    - Open new research avenues in the field of relativistic geodesy providing ultra-precise time and frequency transfer of large distances.
    - High-accuracy observables of non-conservative forces (i.e., atmospheric drag, solar radiation pressure, Earth's albedo, orbital altitude and attitude control forces), provided a precise accelerometer is on board Galileo space vehicles.
    - High-accuracy observations for atmosphere sounding (both ionosphere as well as troposphere).
    - Demonstration of the combined use of both inter-satellite and inter-orbit links.
    - As the above capacities would only be achieved after the full deployment of the satellite constellation. Therefore, during this transition phase, the use of ground based laser ranging stations could become an interim solution to improve the precision of satellite orbits. Subsequently, ground-based laser ranging could also be used in combination with inter-satellite or inter-orbit links.

2) Availability of precise clocks on board GNSS space vehicles and in the ground and user segments is key to improve the accuracy of geodetic and timing products. Some key capacities that could be developed in the frame of future R&D H2020 projects can be summarized as follows:

- Investigate the use of chip scale ground atomic clocks and new conception space atomic clocks. Europe has a long-standing tradition on atomic clock research. Current atomic clocks are based on microwave resonators. R&D efforts should now focus on the development of resonators in the optical wavelengths range and on the industrialization/space qualification of innovative microwave clocks.
- At the GNSS system level:
    - Improve algorithms for fast detection clock anomalies to achieve an enhanced stability and integrity monitoring.
    - Investigate better distribution schemes of the orbit/clock corrections with more precise information and reduced latency.
    - Investigate improved GNSS timing receiver concepts implementing integrity monitoring and providing alerts in case of an anomaly such as jamming and/or outages due to severe space weather events.
    - Investigate the use of new Galileo signals to retrieve precise time products and find technical solutions to account for the ionospheric delay more precisely.

    - Investigate the integration of terrestrial networks of optical fibre (similar concept to that proposed for inter-satellite links) into a GNSS time keeping and distribution concept.
    - Investigate schemes to distribute precise UTC to users in real-time.
  - at the GNSS user level:
    - Envisage more precise calibration methods for multi-constellation multi-frequency GNSS receivers.
    - Investigate the use of receivers specifically designed to facilitate its timing calibration.
    - Integrate schemes to transfer the tropospheric error corrections such that a few cm-range accuracies are achieved. The implementation of such integration through via EGNOS was identified as an interesting and practical solution.
    - Investigate the quality of ultra-stable clocks (both in orbit as at receiver side) to improve point positioning (kinematic precise point positioning, convergence time, height determination…).
    - Tackle the issue of multiplicity of GNSS disseminated time scales pushing for a commonly accepted new standard.
    - Definition of the future GTS ground infrastructure, the associated mandatory requirements and the possible role of each European timing laboratory.

3) GNSS Reflectometry (GNSS-R) is a technique pioneered in Europe that has been successfully demonstrated in various ESA projects and, more recently, in some European Commission FP7 projects. In these projects, the use of GNSS-R receivers deployed in airborne and ground-based platforms has been proven for sea altimetry. The deployment of a LEO constellation with GNSS-R receivers would provide the products such as real-time global wind and wave models, long-term observations of high value for climate change models, precise maps of ice edge and concentration, operational monitoring of sea state, cyclones, and tsunami early warning, among others. NASA is planning to launch the LEO constellation CYGNSS with eight micro-satellites in 2016. ESA is currently investigating the deployment of a GNSS-R payload on board the ISS. Interestingly, GNSS-R offers some very strong synergies between two EU-wide flagship programmes such as Galileo and Copernicus. A significant R&D effort in Europe is now needed to bring this technology to a mature status and be able to catch up. GNSS radio occultation is a technology that has reached a mature status and right now is used operationally to provide precise meteorological products with low-cost payloads on-board Eumetsat/MetOp and NOAA satellites. Taking the history of GNSS radio occultation technology as the baseline for the future development of GNSS reflectometry, the following key capacities could be developed in future R&D H2020 projects:
   - Develop precise orbit determination and precise clock estimation techniques.
   - Investigate the use of alternative frequency bands such as C-band, which would reduce substantially the impact of the ionosphere.
   - Develop new receiver platforms for ground-based stations that could provide innovative meteorological products.
   - Devise techniques to characterize the off-boresight (phase centre) patterns of the satellite antennas.
   - Improve physical models that could bring more valuable products.

- Concept of standard receiver observables (similar to the RINEX standard) to be used for RO and GNSS reflectometry (e.g., based on SDR platforms).
- Investigate digital beamforming techniques to be implemented on LEO platforms to improve the measurements signal-to-noise ratio.

4) 4The need for improved ionospheric and tropospheric models was also identified as a key priority for the future R&D H2020 Calls. This is particularly important to increase the availability and integrity of high precision GNSS products. The capacities that could be developed can be summarized as follows:

- Envisage the use of multi-frequency and multi-constellation GNSS and SBAS combined with the assimilation of complementary real-time observations (e.g., vertical sounding, radio occultation, ground-based/space-based TEC, EUV emissions, solar winds, geomagnetic activity …).
- Investigate the upgrade of current ionospheric delay models (e.g., NeQuick) including a multi-layer mapping function approach for SBAS alternative to the current MOPS thin-shell ionosphere model.
- Investigate the potential of delivering parameters from global and regional numerical weather models (maps of pressure, temperature and specific humidity variations) such that dry and wet tropospheric corrections at cm-level accuracies are reached.
- Improve mitigation and prediction techniques for ionospheric scintillation at low latitudes. Precise positioning GNSS products might be unavailable under ionospheric scintillation and therefore more robust receiver architectures are needed. In this context, the availability of test sites in the Equatorial region (e.g., South East Asia, South America, and Central Africa) is identified as highly important.
- Develop real-time threat models warning of sudden ionospheric gradient variations such that hazardous misleading information is identified and provided to the airborne GNSS receivers for safety critical applications.
- Develop a physics-based data assimilation model of the ionosphere for accurate and reliable specification and forecasting of the ionosphere.

SECTION 4

Summary and Conclusions Plenary Session

In the final plenary session the session chairs presented the main findings of their session.

ANNEX A

List of Acronyms

Acronym	Definition
AD/DA	digital-to-analog/analog-to-digital
ALIVE	alert interface via EGNOS
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
COTS	commercial off-the-shelf
CS	Commercial Service
CYGNSS	Cyclone Global Navigation Satellite System
EC	European Commission
EDAS	EGNOS Data Access Service
EGEP	European GNSS Evolution Programme
EGNOS	European Geostationary Navigation Overlay Service
EIRP	equivalent isotropically radiated power
ESA	European Space Agency
EUV	extreme ultraviolet lithography
H2020, Horizon 2020	The EU Framework Programme for Research and Innovation
HW	hardware
G2G	Galileo 2nd Generation
GBAS	Ground-Based Augmentation System
GCS	Galileo Control Segment
GMS	Galileo Mission Segment
GNSS	Global Navigation Satellite System
GNSS-R	GNSS Reflectometry
GPS	Global Positioning System
GSA	European GNSS Agency
GTS	Galileo Time Service
IGSO	geosynchronous inclined orbit
IPR	intellectual property rights
ISL	inter-satellite link
ISS	International Space Station
LEO	low Earth orbit
JRC	Joint Research Centre
LPV	localizer performance with vertical guidance
M&C	monitoring and control
MEO	medium Earth orbit
MEOLUT	Medium Earth orbiting local user terminals
MetOp	Meteorological Operational satellite programme
MMI	man-machine interface
MOPS	Minimum Operational Performance Standards
NOAA	National Oceanic and Atmospheric Administration
OS	Open Service
PHM	Passive Hydrogen Maser
PRS	Public Regulated Service
R&D	research and technological development
RAMS	Reliability, Availability, Maintainability and Safety
RINEX	Receiver Independent Exchange Format
RLS	Return Link service
RO	radio occultation
RPAS	Remotely Piloted Aircraft Systems
SAR	Search and Rescue
SBAS	Satellite-based Augmentation System
SDR	software-defined radio
SESAR	Single European Sky Air - Traffic Management Research
SIS	signal in space
SME	small and medium enterprise

SOL..Safety of Life
SW...software
TEC..total electron content
TTC..Telemetry, Tracking and Command
UTC..Coordinated Universal Time

ANNEX B

Workshop Agenda

EU Global Navigation Satellite System (GNSS) Research and Technology

Horizon 2020 Stakeholder Consultation Workshop

4 June 2014
Brussels, Belgium

WORKSHOP AGENDA

08:30 – 09:00 Registration

09:00 – 09:10 Opening – Matthias Petschke (European Commission)

Plenary Session – Chaired by Paul Flament (European Commission)

09:10 – 09:30 European GNSS evolution - Hermann Ebner (European Commission)

09:30 – 09:50 Horizon 2020 explained – Tanja Zegers (European Commission)

09:50 – 10:05 An academic perspective – Christoph Gunther (Technical University Munich)

10:05 – 10:20 An SME perspective – Mark Dumville (Nottingham Scientific Limited)

10:20 – 10:35 An industry perspective – Pierre Lionnet (Eurospace)

10:35 – 11:00 *Coffee Break*

11:00 -12.45 Topical Sessions

Galileo Space Infrastructures R&D	EGNSS Services and Mission R&D	GNSS signals R&D
Chair: E. Guyader (EC)	*Chairs: J.P. Boyero (EC) & A. Mozo (GSA)*	*Chair: M. Paonni (JRC)*

12:45 – 13:45 *Lunch Break*

13:45 – 15:30 Topical Sessions afternoon

EGNOS R&D	Galileo Ground Infrastructure and Operations R&D	GNSS Science and Basic Technology Development
Chair: I. Alcantarilla (EC) & C. Villie (GSA)	*Chair: P. Flagel (EC) & H. Faas (GSA)*	*Chair: J. Fortuny-Guasch (JRC)*

15:30 – 16:00 *Coffee Break*

16:00 – 17:00 Summary of topical sessions

17:00 – 17:15 Conclusion and Outlook – Paul Flament (European Commission)

17:15 End of workshop

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GALILEO

EGNOS

ANNEX C

Presentations First Day

Provided as separate file; available on http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_id=7440.

European
Commission