The Interagency Operations Advisory Group (IOAG)
A decade of leadership in International Space Cooperation

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In June of 1999 the space operations leadership of seven space agencies met at European Space Agency (ESA) Headquarters to discuss steps which could be taken to facilitate international space operations strategic planning, including interoperability, which would result in more effective and efficient utilization of combined agency resources. Out of that first International Operations Plenary (IOP-1) the Interagency Operations Advisory Group (IOAG) was chartered. The IOAG -1 was held in February, 2000 and continues to meet at least annually to this day.

In its first decade of operation the IOAG has increased its membership to 11 space agencies and established active strategic liaisons with 4 other international stakeholder organizations. It has enabled international cross support for many missions through establishment and implementation of preferred: standards; services; radio frequencies; and architectures for international space operations and cross support.

The work of the IOAG in advocating these preferred approaches and communicating critical information on government space agency space communications service capabilities has contributed greatly to a significant increase in international space communications cross support over the last decade. Recently this effort has expanded to include information on commercial and academic based providers.

Looking to the future, the group is pro-actively defining the future of space operations architectures through strategic engagement with its members and other international stakeholder groups involving robotic and human exploration architectures, data systems technologies and standards, space radio frequency management and positioning navigation and timing communities.

The paper will describe the first decade of the IOAG's activities, its accomplishments and its challenges in architecting the international space operations cross support systems of today and the future.

1 – Introduction:

International collaboration in space has grown steadily over the past few decades of space exploration. Initial "cold war" competition in space activities gradually shifted to more open scientific and human exploration to the point that international collaboration in science and human flight missions is now the norm in today's world. Cooperation in space missions continues to be driven by political and technical reasons as well as very practical considerations such as the substantial cost of space exploration, which is easier to accomplish when the cost is distributed across several partners.

Initial collaboration started with the sharing of scientific data, hosting of other nations scientific instruments and launching of other agency spacecraft. It soon expanded into providing cross support tracking and navigation capabilities for partner missions. Initially this support was coordinated via bi-lateral agreements between agencies via Inter Agency Tracking Communications and Operations Panels (ITCOPs). Gradually, it was recognized by several agencies that multi-agency coordination on topics such as radio frequency spectrum, space data standards and ultimately the strategic planning of operations architectures was essential to facilitate effective utilization of space. Accordingly the international space community formed the Space Frequency Coordination Group (SFCG) and the Consultative Committee on Space Data Standards (CCSDS) to coordinate spectrum and data standards respectively. These organizations have been functioning effectively for over 30 years.

In the late 1980's/early 1990's the multi-lateral Space Network Interoperability Panel (SNIP) was chartered to achieve data relay satellite compatibility/interoperability for ESA, NASDA and NASA. The SNIP was very successful and produced a baseline set of frequencies and standards for Interoperable use with space relay systems. Its work has facilitated effective multi-agency participation in the servicing of the International Space Station as well as cross support to several robotic scientific spacecraft including ETS and ALOS.

In 1998 ESA, the Institute of Space and Astronautical Science (ISAS), NASA and the Russian Federal Space Agency (RFSA) joined together to begin to tackle the international coordination of space communications cross support architectures by forming the Inter-Agency Consultative Group (IACG), Working Group-4. This group was a subset of the IACG, which dealt with collaborative activities for space science missions. Its work was initially focused on the Giotto mission and it was chartered to recommend specific actions needed to facilitate cross support of one agency's space science spacecraft by another agency's space communications facilities. This WG leveraged the work of the SFCG and the CCSDS groups to accomplish its purpose. The successful cross support to the Giotto mission set the stage for a more global approach to this challenge, such as Cassini.

The leadership of several space agencies recognized the benefit of these multi-lateral efforts and resolved to consider a more comprehensive multi agency approach to space communications planning. Accordingly, the space operations leadership of seven space agencies met at ESA Headquarters in June of 1999 to discuss steps which could be taken to facilitate international space operations strategic planning, including interoperability. Out of that first International Operations Plenary (IOP-1) the Interagency Operations Advisory Group (IOAG) was chartered.

The IOAG was chartered to be the main international body to oversee the development of collaborative, interoperable space communications and navigation services for the benefit of all members' spaceflight missions.
Specific instructions from the first charter included:

1. Recommend specific actions needed to facilitate cross-support of one agency's spacecraft by another agency's support facilities;
2. Study interoperability issues in particular with respect to tracking, telecommand, telemetry data acquisition systems, as well as utilization of frequency bands;
3. Maintain an effective liaison to CCSDS and SFCG and make recommendations for priority standards development.
4. Draw on the technical work already completed by other organizations developing standards for space systems such as CCSDS and SFCG;
5. Make an analysis of the future demand for Ground Tracking and Data Acquisition Facilities and maintain related Mission Model and Tracking Facilities Inventory
6. Evolve Compatible Space Communications Architectures

The first IOAG meeting (IOAG -1) was held in February, 2000 and the group continues to meet at least annually to this day.

2 – History of Membership:

The IOAG started out with membership from seven space agencies including: Agenzia Spaziale Italiana (ASI), Centre National d'Etudes Spatiales (CNES), Deutsches Zentrum fur Luft- und Raumfahrt (DLR), European Space Agency (ESA), the Institute of Space and Astronautical Science (ISAS), National Aeronautics and Space Administration (NASA) and National Space Development Agency (NASDA). Over time it has evolved to reflect changes in the world space organizations and add new members. The first change was due to the subsequent merger of ISAS and NASDA into an integrated Japanese Space Agency, Japan Aerospace Exploration Agency (JAXA).
In 2007 the Indian Space Research Organization (ISRO) and in 2009 the RFSA joined the organization. Members of the IOAG are required to be space agencies having a substantial scientific space program,

which have the capability and assets to provide cross support to international space missions. Historically, as well as today, all members meet this requirement.
Additionally the organization decided to allow observers to participate in the activities starting in 2009 adding the China National Space Agency (CNSA), the Korean Aerospace Research Institute (KARI) and the newly formed United Kingdom Space Agency (UKSA). Agencies which do not meet the mentioned requirements for full membership, but want to participate in the IOAG work, can become Observer Agencies. Observer status allows for the IOAG and the observer agency to evaluate the agency benefit as well as their potential contribution to the IOAG.

IOAG functions on a quorum of its members. Therefore Full Members Agencies have to attend the meetings and agree to follow the decisions recorded in the IOAG recommendations. IOAG tries to make its decisions on a consensus basis. Any decision by the IOAG requires a 60 percent of the Full Members approve.

It should be noted that IOAG Membership cannot be fully aligned to membership of all organizations in interface. Membership to IOAG remains on a voluntary basis, but new IOAG members have certain obligations:

- An agency seeking membership in the IOAG agrees to comply with all previous recommendations made by the IOAG and all relevant standards adopted by the CCSDS, SFCG, and such other organizations as the IOAG shall designate.

- Also, to maintain efficiency, the IOAG will consider for membership those agencies which have significant relevant mission and/or ongoing space communication activities.

3 – Organization

The processes and methods for operation of the IOAG are defined in the Procedures Manual[i]. It documents the objectives, organization, participation and operations of the IOAG.

The IOAG operates as per the instructions and guidance formulated at the last IOP meeting. At regular steps, the IOAG reports to the IOP on the progress made. A new IOP meeting will be called by the IOAG when the assigned tasks are considered completed, when commitments are required from the agencies for future developments or when new guidance is needed to define the next orientations of the IOAG activities.

Organizational functions within IOAG are
- chairman,
- secretary,
- heads of delegation,
- liaisons,
- technical subgroups.

At IOP-2 (December. 2008) a chairman was installed to ensure working continuity between the meetings, which take place once a year. Since the IOAG formation NASA has provided the IOAG secretariat, which shall assist the chairman in the orderly functioning of the IOAG. IOAG work can be followed on IOAGs Web page (www.ioag.org), which is served by the Secretariat.

Member agencies are expected to assume the following, in order to affect an efficient IOAG process :
1. Each agency is required to appoint a Head of Delegation (HoD) who is authorized to speak for, and make commitments on behalf of the agency, which he or she represents.
2. Each HoD must monitor and report on the status of the requirements from missions in which its agency is involved (through ITCOP or other bi/trilateral agreements) and in which cross-support are planned
3. Each HoD must coordinate at the technical level with the operations coordination groups, to inform them of the agencies network status and planned changes, as reported at the IOAG;

[i] IOAG Procedures Manual: https://www.ioag.org/Public%20Documents/IOAG%20Procedures%20Manual.pdf

4. Each HoD must monitor the status of the work of relevant standards organizations and identify the areas not or not sufficiently covered, considering the requirements of the upcoming missions;
5. Each HoD must coordinate at the technical level with the representatives of its agency in the relevant standards organizations in order to inform them of the outcomes of the IOAG in terms of priorities or implementation difficulties.
6. Each Member Agency, through its IOAG / IOP delegates, must rely on or put in place an internal organization that enables consistent decisions and actions within its agency.

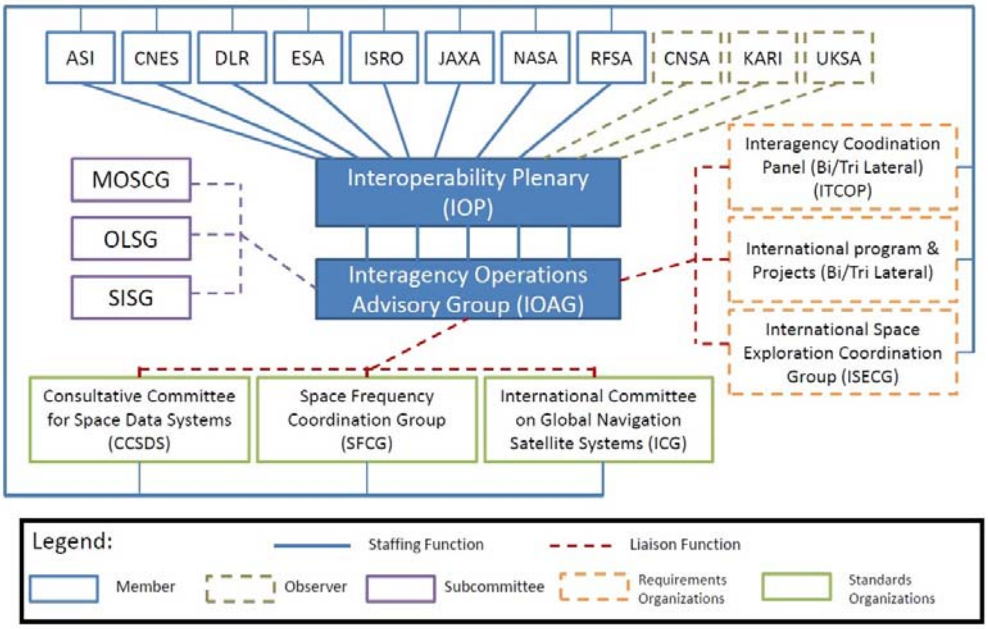

Figure 1: IOAG Organizational Relationships

On a permanent basis IOAG Agencies review their capabilities, develop a roadmap leading to interoperability, identify areas where standards are needed and communicate this information to the relevant organizations (CCSDS, SFCG, ICG, ILN, ISECG). Iteration with these entities has proven fruitful for all parties and ensured strategic alignment to maximize the collective effort. For its liaisons with such organizations, IOAG defines points of contact proposed by its members. These people will stay in close relationship with the liaison partner organization to keep the information flow alive.

For special tasks IOAG can form Subgroups of member Agencies, who are parties-in-interest to these tasks, to complete the work. Examples are the Space Internetworking Strategy Group (SISG), the MOSCG (Mission Operations Systems Coordination Group) and the Optical Link Study Group (OLSG). These groups were co-chaired by two IOAG member agencies and involved significant effort from the technical staff of member agencies as well as CCSDS technical personnel. The objectives of these groups are to explore new domains for interoperability, to collect mission needs from projects and international user organizations, to establish mission models and operations concepts for these domains and to elaborate high level requirements to the standardization organizations for the development of the corresponding architectures.

IOAG publishes annual reports[ii] and updates the tables of the IOAG members on their Communication Assets and Mission Models on a permanent basis.

4 – Objectives

The IOAG will undertake activities it deems appropriate related to multi-agency space communications. A specific IOAG goal is the achievement of full interoperability among member space agencies. The May 2009 version of the Terms of Reference[iii] (TOR) establishes the framework agreement under which the IOAG shall operate. The activities below define the current scope of IOAG activities and the methods used to accomplish that work.

ToR (a) Identifying the space and ground networks support capabilities needed by potential cooperative programs and projects to achieve their scientific objectives.

ToR (b) Maintaining a list of interoperable facilities and services operated by the space agencies.

ToR (c) Promoting the use of internationally recognized standards in the design and implementation of cooperative flight programs including: spacecraft, ground and space networks.

ToR (d) Monitoring the work of relevant standards organizations and assisting in the agreement, adoption and implementation of new standards by space agencies.

ToR (e) Identifying inconsistencies in the data transmission, capture, handling, and processing systems used by agencies. The IOAG should inform relevant standards organizations (such as the CCSDS or the SFCG) of these inconsistencies, using methods described in the IOAG Procedures Manuals, as well as IOP Members, inviting them to undertake the development of new international standards.

ToR (f) Establishing priorities for the implementation of systems and services needed to achieve full interoperability and enunciating policies furthering interoperability. Such priorities should be passed to relevant organizations and to the IOP Delegations.

ToR (g) Assessing the resources needed to implement these requirements and urging IOP Delegations to make these resources available within their agencies.

ToR (h) Defining and maintaining a reference architecture that will enable interoperability and cross support across space agencies.

ToR (i) Encouraging the distribution of communication and navigation techniques to accelerate the deployment of interoperable solutions.

At the 2nd Inter-Operability Plenary meeting (IOP-2), held 8-10 December 2008 in Geneva, Switzerland, additional objectives of the IOAG for the upcoming years were established. As the parent organization of the IOAG, the IOP-2 adopted the following resolutions:

IOP 2 (1). The IOP charges the IOAG to continue as the international focal point for fostering and leading interoperable space communications and navigation matters for cross-support of spaceflight missions.

IOP 2 (2). The IOP considers it as strongly beneficial for the IOAG to admit Membership of those Agencies having significant and relevant missions and assets respectively requiring and providing space communications and navigation cross-support The IOAG is encouraged to invite observers from other Agencies to participate in IOAG meetings as deemed necessary.

IOP 2 (3). Furthermore, IOAG organizational processes should be adapted to collect and process in a timely manner all the space communications and navigation requirements of other international space coordination groups (e.g., the International Space Exploration Coordination Group [ISECG], International Lunar Network [ILN], and international Mars

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[ii] 2011 IOAG Annual Report: https://www.ioag.org/Public%20Documents/IOAG.A.AR.2011.001.V3.pdf
[iii] Terms of Reference : https://www.ioag.org/Public%20Documents/IOAG%20Terms%20of%20Reference.pdf

exploration, inter alia), and to provide strategic guidance to the relevant standardization organizations. This includes the CCSDS and the Space Frequency Coordination Group (SFCG).

IOP 2 (4). The IOAG's ground-based Cross Support Service Catalog should be completed and agreed by all IOAG participants in order to establish a common basis across the Agencies for the consolidation of ground-based cross support by 2012. Agencies should agree to implement IOAG recommendations for missions, which may benefit from cross-support and/or international cooperation. It is an IOAG goal to have a plurality of the participating Agencies capable of providing ground-based cross support of an agreed common IOAG Service catalog by the end of calendar year 2015.

IOP 2 (5). In order to achieve an enhanced end-to-end cross support service catalog that will provide the platform of standardization for extending cross support into space, the IOAG should prioritize the requirements relevant to space communications interoperability and cross-support and should urge the CCSDS to adjust their work accordingly. IOP-2 recognizes the authority of the IOAG to prioritize future work as necessary.

IOP 2 (6). The SISG should formalize a draft Solar System Internetwork (SSI) Operations Concept and candidate architectural definition in time for IOAG-13 and should prepare a mature architectural proposal for review and endorsement at the third Inter-Operability Plenary meeting (IOP-3). At that time, the IOAG is requested to present an enhanced service catalog for endorsement. The IOP Agencies should ensure representation from their programs and projects to work with SISG to identify potential missions that may benefit from adoption of the SSI-related standards, leading to a gradual build up of in-space and ground-based space internetworking infrastructure.

IOP 2 (7). In the course of its deliberations, the IOP-2 was encouraged by the progress made to date, and stressed the importance of safeguarding the achievements made throughout the past years in cross-support and interoperability, in particular, maintaining compatibility with prior recommendations.

5 – Interfaces with other international organizations

After the IOP-2, the IOAG was chartered to be the sole international body to coordinate the development of collaborative, interoperable space communications and navigation service definition of participating agencies to support agency flight missions with strong interaction to SFCG, CCSDS, Users and Projects/Programs (see Figure 2).

Agency delegates in the IOAG must then be knowledgeable in all areas of space communications and navigation that are discussed in the liaisons with user communities and projects on the requirements side and areas and working groups of the standardization bodies. The intent of the Agency's leadership was to avoid duplication of working groups of these other bodies.

The objectives of the coordination with the international projects and with the user communities, such as the International Lunar Network [ILN] or the International Space Exploration Coordination Group [ISECG], are to collect requirements from such organizations but also to make sure that the IOAG recommended architectures are taken into account in the definitions for the future international programs in which interoperability is required. The main outcomes of this coordination are a common vision of the infrastructures that will support the future missions and the confidence that they can be shared by agencies and be re-used by multiple missions, based on the agreed set of supporting standards as recommended by IOAG.

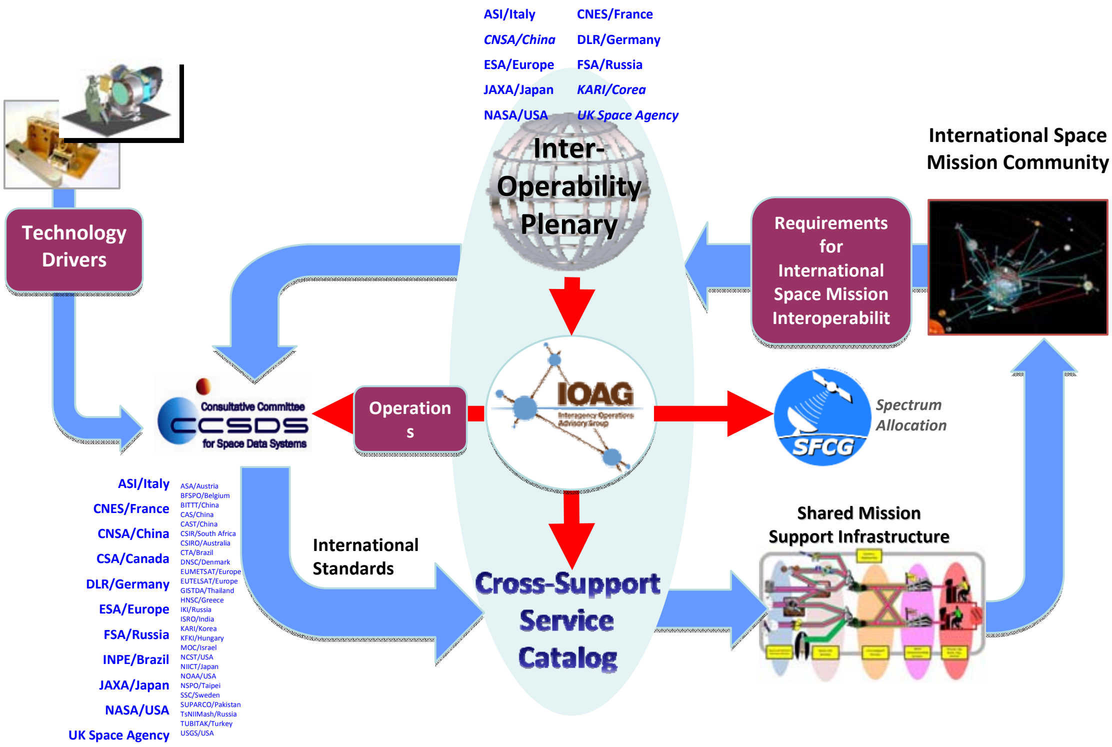

Figure 2: IOAG central role.

The objectives of the coordination with the standardization organizations, such as the SFCG, the CCSDS or the ICG, are to relay to these organizations high level requirements for the development of new standards and priorities for the development of the standards needed by the projects.

Recommendations to the CCSDS via Liaison statements, was the standard operating method for the first decade. Specific recommendations were made for focus areas. For example, Space Link Extension (SLE) services related to telecommand and telemetry transfer, service management, file transfer mechanisms, and radiometric data services were given appropriate priorities from the space system operator's perspective. Thus the CCSDS was made aware of specific user needs for planned and envisaged space missions and systems and allowed CCSDS to focus their limited resources towards timely provision of standards and recommendations. The CCSDS Engineering Steering Group (CESG) Chair / Co-Chair were appointed as the permanent liaisons to the IOAG and routinely brief the IOAG on CCSDS activities and status. This is expected to reduce the number of liaison statements and to improve the quality and completeness of the messages between the two organizations.

The formulation of the IOAG requirements has improved with the work of the technical subgroups who produced documents with valuable and sufficient technical contents to be directly useable by the standardization working groups. To avoid duplication, it was decided that the IOAG technical subgroups would only produce models and operations requirements, while the standardization working groups would develop the required communications architectures.

6 – Achievements

The IOAG has enabled member agencies to make more efficient use of their resources thru effective leveraging of member tracking and communications assets. It has also allowed agencies to lower their mission risk by virtue of the international community of emergency support stations, which has been enabled by the IOAG's efforts. The organization has addressed each one of the chartered responsibilities over its first decade of operation and in some cases ventured beyond them in order to facilitate spaceflight cross support and operational coordination among members. Some of the major achievements with illustrative examples follow:

Frequency band co-ordination and Liaison with the SFCG:
The S-Band frequency utilization in deep space band (2110-2120 MHz) was significantly affected by IMT-2000 (UMTS mobile phones). This interference was anticipated to get much worse in the future with the explosion of mobile devices in some geographical areas. Accordingly, the IOAG recommended that future deep space missions and ground facilities be based on X-band and Ka-band usage. This recommendation has been widely accepted among the IOAG agencies. For example Rosetta amended its on-board and ground facilities to also include X-band up-link (7145-7235 MHz). Similar changes have been made to NASA, JAXA and other agency tracking facilities. Today, most deep space (greater than 2 Million Km from the Earth)are planning to utilize Radio Frequencies in X and Ka Bands. In fact many operational deep space missions already routinely operate in X and Ka Bands.
A critical step in developing recommendations for frequency bands and getting missions to adopt them is to ensure very close coordination with SFCG. This has been the case between the IOAG and the SFCG. The SFCG participates at least once a year in IOAG meetings and each IOAG member agency works with their SFCG and spectrum management representatives to influence their governments to adopt positions consistent with the IOAG/SFCG recommendations. This coordinated effort carries thru all the way to the World Radio Conferences sponsored by the International Telecommunications Union (ITU). It should be noted that the IOAG agencies still plan to use S band for many Earth orbiting and legacy deep space missions for the foreseeable future.

Mission set and ground tracking facility coordination:
Cross support possibilities have been facilitated by the compilation of mission set and ground tracking facilities for the IOAG agencies. These are updated annually to ensure currency. Recently, the support facilities of the growing commercial and University space communications providers have been added further enhancing the value of the information. This data is available on the IOAG website and also includes the infusion status and plans for IOAG recommended standards at member facilities. This compilation of relevant cross support information has greatly simplified and eased the consideration of possible cross support partners for any particular spaceflight mission. If a member agency needs coverage in a particular geographic area for mission launch and early orbit support or to handle a peak network load period, a quick review of the IOAG asset data base would identify several agency or commercial antennas which could provide the needed frequency band and technical performance with an internationally standardized interface.

Additionally, these data sets have been most beneficial for member agency strategic planning with respect to future tracking capabilities. For example, a member agency can easily obtain the data to make a reasoned decision to pursue the use of the capability of an IOAG member, a commercial or university provider, or their own antenna to meet a particular need.

The IOAG also provides an effective forum for sharing experiences and enabling an interchange on future plans. Of particular note have been discussions on options to improve the efficiency of existing assets through utilization of techniques such as: Ka-band frequency (on-board and ground systems); Efficient coding schemes (Turbo and Low Density codes); Multiple Spacecraft per Antenna; Bandwidth efficient modulation for higher data rates (GMSK); and Delta-Differenced One-way Range (Delta-DOR).

The IOAG deliberations and experiences have also pointed out the International importance of certain unique assets which provide a critical spaceflight health and safety or science capability such as very large (>60 meter) deep space antennas with very high Sensitivity and Effective Isotrophic Radiated Power (EIRP) and space relay systems for missions which demand low latency and / or near continuous coverage.

Cross-support service standards (Telemetry and Command):
In the pre-IOAG era cross-support services typically were achieved via dedicated protocol converters or network data interface units varying from project to project. This was complex and costly to all agencies involved in the cross support and was the source of additional complexity and risk in the execution of cross support. Improvement in this area was a high priority for the first few years of the IOAG. Accordingly, it

worked with all member agencies to adopt the CCSDS Space Link Extension (SLE) transfer services as enabler for cross-support.
Command Link Transfer Unit (CLTU) forward service, Return All Frames (RAF) and Return Channel Frames (RCF) return services were implemented for INTEGRAL, ROSETTA, Mars Express, Venus Express, MUSES-C. Initially NASA was acting as an SLE provider, with ESA and JAXA acting as SLE user entities. ESA has since expanded its capability to act as provider (e.g. Phoenix LEOP). Today NASA, ESA, CNES, DLR and JAXA tracking networks are SLE compatible. SLE is used to support missions from the International Space Station (ISS) via data relay satellites, to Earth observation and lunar missions via ground networks to the family of Mars missions thru deep space tracking stations. Further many manufacturers of commercial equipment have included SLE compatibility in their standard products making it very cost effective to implement this capability. Additionally many commercial and university space communications providers have adopted SLE compatibility.

Radiometric data exchange:
Prior to the formation of the IOAG, no internationally agreed to standard was available for exchange of radiometric data products, such as antenna pointing predictions and orbit determination. The IOAG recommended CCSDS make it a priority to develop standards in these areas. The CCSDS subsequently established blue and green books covering related services (Orbit, Attitude and Tracking Data Messages), intended for future implementation. Agreements were also reached on Delta-Differenced One-way Range (Delta-DOR) technique related standards.

Space Internetworking:
The focus of activities aiming at interoperability traditionally had been at the two bottom layers of the ISO communications reference model, i.e., they dealt with the physical layer (e.g. RF and modulation) and the link layer (e.g. packet TM and TC enhanced by SLE) as to enable point-to-point communications. The successful demonstration of multi-hop communications at Mars (e.g. NASA rovers communicating with earth via an ESA orbiter) and the advances in communications technology (Delay Tolerant Network (DTN)) suggested to explore the possibility of moving the space communication and operation paradigm from the conventional link layer to a network centric approach. IOAG-11 resolved in 2007 to form a Space Internetworking Strategy Group (SISG) that was chartered to study internetworked space operations to some detail with the objective of presenting a report on the findings at the IOP-2 in December 2008. The SISG involved agency technical personnel with extensive CCSDS experience and was led by senior delegates from the IOAG.

The SISG in completing its Phase 1 activities released the report "Recommendations on a Strategy for Space Internetworking" in November 2008. In the light of this report, IOP-2 requested SISG to formalize a draft Solar System Internetwork (SSI) Operations Concept and to prepare a mature architectural proposal for review and endorsement at the third Inter-Operability Plenary meeting (IOP-3). This drove the SISG to undertake its Phase 2 activities. These included a series of in-depth studies of specific SSI issues and the development of an SSI Operations Concept. At the completion of Phase 2 in 2010, SISG released two new documents (Solar System Internetwork [SSI] Issue Investigation and Resolution [iv] and Operations Concept for a Solar System Internet [v](SSI)) and re-issued the 2008 report with various updates and clarifications as to align it with the outcome of the Phase 2 work.

As regards the development of an SSI architecture, the IOAG-14 concluded that CCSDS would be better placed to perform such work, as some related activities were already on-going within CCSDS, both in the Cross-Support Services and the Space Internetworking Services areas. While the former works on a generic architectural framework, the latter focuses on the SSI architecture. The activities of the groups are complementing each other and can therefore proceed in parallel without conflict.

[iv] SSI Issue Investigation and Resolution :
https://www.ioag.org/Public%20Documents/SSI%20Ops%20Concept%20Issue%20Resolution%20-%20final%20version.pdf
[v] Operations Concept for a SSI : https://www.ioag.org/Public%20Documents/SISG%20Operations%20Concept%20for%20SSI%20-%20final%20version.pdf

Service Oriented Architectures (SOA) and Service Catalogs:
The IOAG, working with the CCSDS is moving towards a SOA approach for space communications architectures and cross support. In the past few years the IOAG has decided to document its recommendations for cross support into cross support service catalogs.

As a specific IOAG goal is the achievement of full interoperability among member space agencies, concurrently with SISG activities, a dedicated Working Group was tasked to complete and agree a catalog of consolidated ground based cross-support services with a near term and a long term view.

For the near term, IOAG identified ongoing and already defined services with the implied objective that the plurality of the IOAG agencies shall be capable of providing these services around 2015. Such a Catalog is referred to as "IOAG Service Catalog #1[vi]" where mandatory and Optional Services have been identified. For the long term, IOAG specified an enhanced catalog covering end-to-end services and extending cross-support into space as driver for further CCSDS standardization efforts. Such enhanced catalog is referred to as "IOAG Service Catalog 2[vii]" .

From a practical point of view, while IOAG Service Catalog #1 addresses current mission scenarios where access is provided to a single space/ground data link.

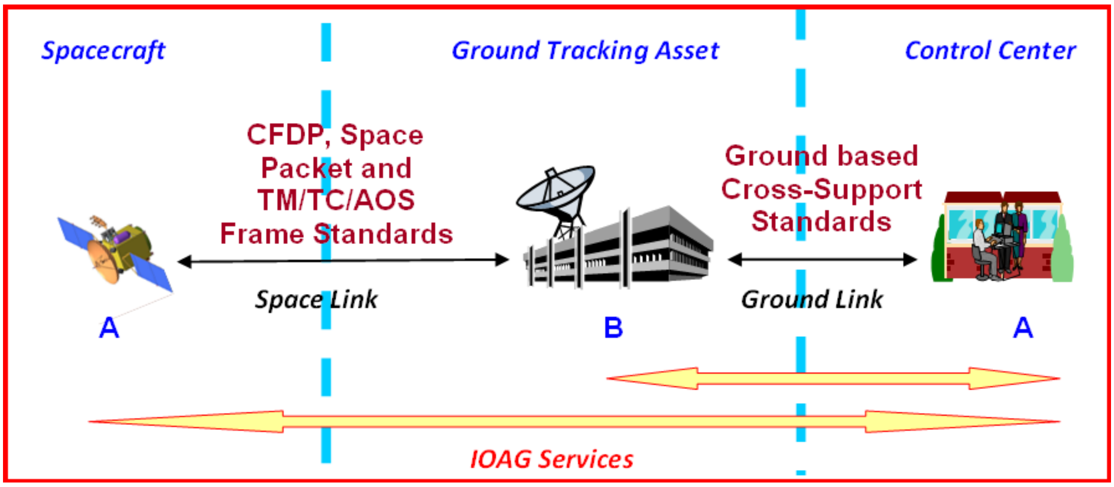

Figure 3: Cross Support configuration in the IOAG Service Catalog#1

Within IOAG Service Catalog #1 three "core" IOAG services have a prominent position as they are fully implemented and rely on the draught-horses of cross support; i.e. Forward CLTU Service, Return All Frames Service, and Return Channel Frames Service.

IOAG Service Catalog #2 addresses space communication services for in-space relay and network cross-support scenarios which would enable future Solar System Internetworking (SSI); i.e. Catalog #2 comprises typically Delay/Disruption Tolerant Networking (DTN) and / or Internet Protocol (IP) technologies.

Groups of IOAG Services, including several service types, have been identified in Catalog #1 and eventually completed in Catalog #2 with additional services relevant for SSI. They are Forward Data Delivery Services Group (services allowing transfer of data from a control center to a spacecraft), Return Data Delivery Services Group (services allowing transfer of data from a spacecraft to a control center), and Radio Metric Services Group (services allowing the results of radio metric measurements to be provided to a control center). In addition, Service Management functions are defined to allow for interaction between

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[vi] Service Catalog 1: https://www.ioag.org/Public%20Documents/IOAG%20Service%20Catalog%201.pdf
[vii] Service Catalog 2: https://www.ioag.org/Public%20Documents/IOAG.T.SC2.2011.V1.0.pdf

the space agencies in order to coordinate the provision of the above space communications and radio metric services.

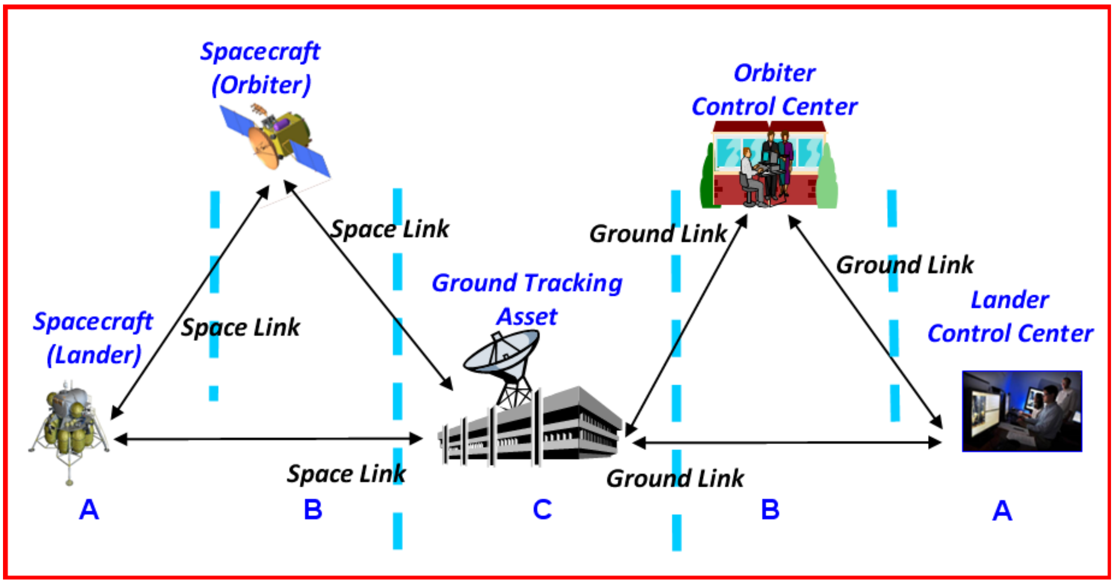

Figure 4: Cross Support configurations in the IOAG Service Catalog#2

The definition of both Catalogs implied identifying possible deficiencies in existing set of standards and generating associated guidance to CCSDS for those standards that are either in progress or to be started. This exercise highlighted the need for proper reporting of the CCSDS activities with respect to IOAG requirements. The implementation of the "IOAG-CCSDS Product Agreement[viii]" (ICPA) a simple and effective web tools that provides reporting art "CCSDS Standard Level" with the possibility of bilateral commenting by either CCSDS or IOAG is in development to meet this need.

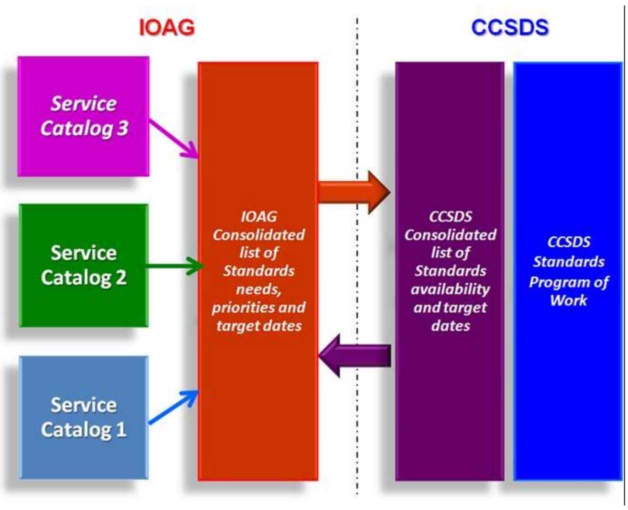

Figure 5: Principles of the IOAG CCSDS Product Agreement (ICPA).

Most of the ICPA information is directly derived from the CCSDS database of approved in-work documents and connected to IOAG input and priorities. This also allows accessing history for checking individual Projects. IOAG can revise priorities at any time as well as CESG can revise response to IOAG at any time while at each meeting (typically spring and fall), each organization should review changes to ICPA since last meeting.

[viii] Web based ICPA : http://cwe.ccsds.org/fm/Lists/Projects/IOAG.aspx

The IOAG is developing prioritization guidance for the development of each standard, based upon member agency strategic needs. This prioritization is provided to the CCSDS as consensus is reached among IOAG members (see next section). Target dates associated to the IOAG priorities refer to the IOAG mission models and to the identified opportunities for implementation of the new standards.

To some extent, the best measure of success for the IOAG is the increasing use of cross support for member nations. Adoption of internationally interoperable standards by missions and ground systems of member agencies is the key. Figure 3 shows the trend in adoption of one of the primary sources of international standards of the CCSDS by space missions around the globe. During the IOAGs first decade the use of CCSDS standards has increased about 6 fold and is reflective of an increase in cross supported missions.

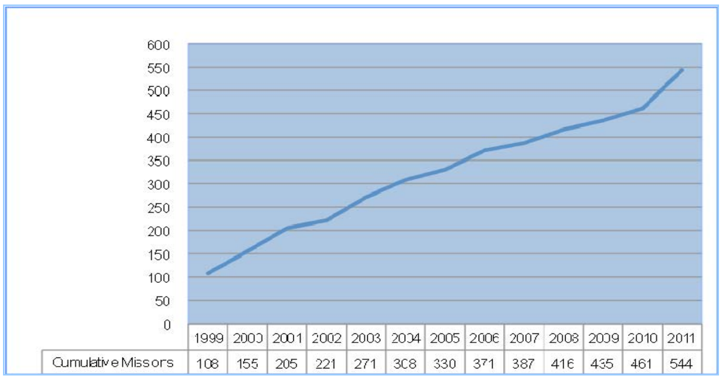

Figure 6: Number of missions using CCSDS standards vs. time

7 – Next challenges and preparation of the future

To cover the need of future operations IOAG will have to continue its coordination with the requirements and the standardization organizations in order to identify the needs and the priorities in the development of new mission concepts and their implementation plans.

As technology available for space mission operations has evolved, new mission operations concepts have been proposed by several agencies, which push the envelope beyond traditional cross support capabilities. Therefore, the IOAG is leveraging these new technologies to improve space communications capabilities and enable these new mission concepts.

Prioritization of activities in general and prioritization of the development of standards will remain a critical activity of IOAG as it is a key driver for the utilization of resources to prepare for the future.

Some of the main activities currently on the agenda of the IOAG are summarized hereafter, with indication of their status and plans:

IOAG Top Priorities:

Recently since 2010, the IOAG has had several discussions on the priorities concerning cross support services and relevant standards. IOAG priorities apply to two areas:

- Category 1 - IOAG Top priorities that are to reflect the common vision of the domains on which the IOAG should put their highest priority of actions, whether they relate to the need for common choices, to the need for new standards or to the urgency for deployment of new technologies;
- Category 2 - IOAG priorities for development of new standards, as specifically identified in the "To Be Written" category in the IOAG Service Catalog#1 and 2.

The following domains were identified as belonging to the first category of IOAG Top Priorities:

- Conjunction data message: standard in preparation at CCSDS
- LDPC codes (3 mission models): standards available and in preparation at CCSDS
- Delta DOR: standards available and in preparation at CCSDS
- Mission Operations Core Services: standards available and in preparation at CCSDS
- Service Management: standard available and "under revision“ at CCSDS
- CFDP: standard available and implementation standards (CFDP over xxx) under discussion in CCSDS
- Space Data Link Security: standard in preparation at CCSDS.

Concerning the second category of IOAG priorities, i.e., that for the development of new standards, the exercise conducted by the delegations was for those yet-to-be-written standards in both IOAG Service Catalog #1 and Service Catalog #2. The outcome of this exercise provides indications of target dates when the standards should be available so that the opportunity exists for at least one of the IOAG agencies to use it in its future implementations it forms a direct input of IOAG to the ICPA.

The following prioritization and target dates were established:

Priority 1: CORS, CFXS, DTN-S

- CSTS Offline Radio Metric Service [CORS] : 2014
- CSTS File Transfer Service [CFXS] : 2014
- Three DTN-related standard protocols [DTN-S]: 2018
    - Bundle Protocol Specification for CCSDS
    - Bundle Security Protocol for CCSDS
    - LTP Specification for CCSDS

Priority 2: EDM, DDORS, FSEF, DTN-M, FF, SSI-CP

- CSTS Engineering Data Monitoring [EDM] : 2016
- CSTS Delta DOR Service [DDORS] : 2018
- SLE Forward Synchronous Encoded Frame Service [FSEF] : 2018
- DTN-related network management standard [DTN-M]: 2018
    - Bundle Protocol Network Management
- CSTS Forward Frame Service [CFFS] : 2018
- SSI Contact Plan Standard [SSI-CP] : 2018+

Priority 3: all others

The above lists are to be brought to the attention of the IOAG agency management and to the international organizations in interface, in particular CCSDS, with the objective to integrate this common vision of the IOAG agencies in the decision processes, including in terms of resource allocation.

Cross support services:

SLE Services have been the starting point of easily controlling spacecrafts through third party ground systems. With reference to the IOAG Service Catalog#1, these can be improved by service management and by services not only extending the space link services between spacecrafts and ground stations. Other services such as generic file transfer services and monitoring services, to deliver monitoring information on the ground stations to the users, are part of the new services for which standards are now expected from the Cross Support Services (CSS) Area of CCSDS.

Future space exploration concepts will introduce much more complex topologies, as identified in the IOAG Service Catalog#2, with data transfer over multiple hops via relay spacecrafts and other intermediate nodes. Such scenarios call for the implementation of a Solar System Internetwork (SSI), with the introduction of a network layer in the space communication protocol stack to provide reliable routing and forwarding of data across multiple links.

As a development of the IOAG SSI Operations Concept, four standards will be developed by CCSDS to provide the complete architectural vision of the SSI :

- SSI Operations Concept – Green Book (the IOAG/SISG document encapsulated in a CCSDS standard)
- SSI Architectural Framework – Green Book (introduction to the DTN suite)
- Cross Support Services Architecture, Concepts and rationale – Green Book
- Cross Support Services Architecture, Architectural definition – Blue Book (reference architecture)

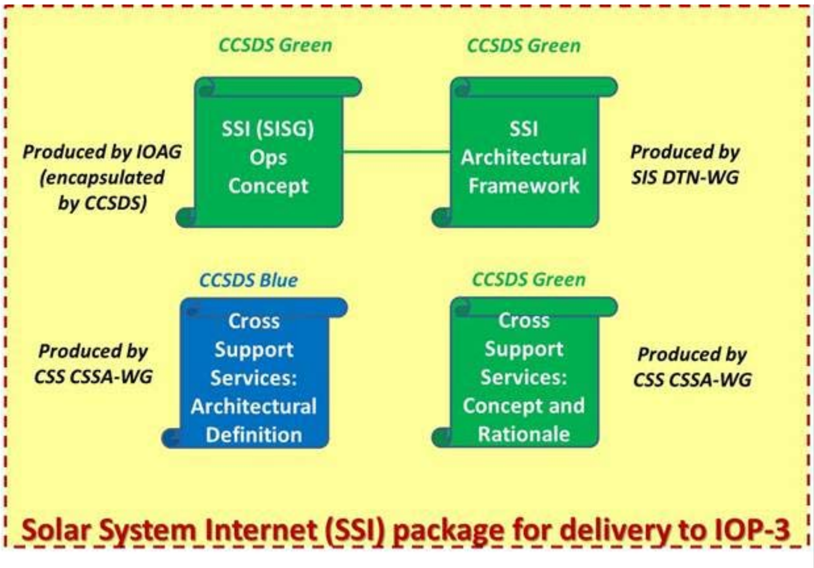

Figure 7: Suite of Standards for the definition of the SSI Architecture

As regards the development of standards dealing with the protocols required for the SSI, the refinements of the DTN protocol suite as needed to adapt it to the specific requirements of the space communications environment are being developed. Both the Bundle Protocol (BP) and the Licklider Transmission Protocol (LTP) of the DTN protocol suite underwent a first round of agency review and therefore the publication of the final CCSDS standards can be expected for the near future. The standard for the transfer of IP datagram's over CCSDS link layer protocols will be released this year.

A set of SSI network management activities will be needed to support the operations of the SSI network layer. Key elements include

- management of the SSI network address space
- determination of the SSI contact plan (i.e., the temporal connectivity of the overall network)
- dissemination of the SSI contact plan to all participating SSI nodes,
- monitoring of the SSI network performance and
- identification and resolution of any detected network anomaly.

Optical Communications:

Optical communications offer several significant advantages such as higher data throughput for the same flight size, weight and power. Around 2008 several organizations (including several IOAG member agencies) demonstrated (or were developing demonstrations of) optical communications systems in space. Further, they were beginning to plan for deployment of optical communications into operational space communications systems. Unfortunately, different agency needs were driving different and incompatible approaches. Optical communications was also an ideal candidate for cross support due to its need for site diversity to overcome cloud cover challenges.

The IOAG therefore decided to charter an Optical Link Strategy Group (OLSG) to set the basis for an optical communications and tracking architecture with an operations concept and required standards for optical cross support. The scope was to cover several mission domains from Near Earth to Deep Space scenarios, including direct to Earth, relay or inter-satellite links. Similar to the approach used for the SISG, this group was led by senior IOAG delegates, and staffed by domain experts and CCSDS knowledgeable persons. The standards they are calling include all aspects of the end-to-end links such as wavelength, modulation, coding and protocols. This OLSG is nearing completion of their task as this paper was being written and their results will be presented in a separate paper[ix].

Mission Operations:

Over the past few years the IOAG has examined topics in the area of mission operations to enhance member agencies mission success. Recent examples of topics discussed at IOAG meetings include collision avoidance, and mission operations systems architectures. These have been at times very hot topics on the agendas of many member agencies.

Mission Operations Services as such were first introduced into IOAG on its Rome meeting September 2009. Despite the fact that the IOAG charter does not explicitly include mission operations, the IOAG formed a coordination group to investigate potential IOAG coordination of Mission Operations Architectures and standards. This Mission Operations Systems Coordination Group (MOSCG) will make recommendations to the IOAG members with respect to IOAG involvement in Mission Operations. These would subsequently be considered for discussion at IOP-3, in particular to decide whether the scope of the IOAG should be expanded to embrace mission operation functions. An IOAG service catalog #3 could include such mission operation services.

Service Concepts are today used in many big software developments. Within IOAG the standard, which is currently defined in CCSDS, is said to be the basis for future operational concepts and implementations for space operations. Challenges include different operational concepts among the agencies as well as limited resources to come up with an IOAG agreed concept for mission operation services. Some IOAG members advocate for a slow progressive approach of the domain while others support the idea of a more significant involvement of the IOAG with the formation of a Mission Operations Systems Strategy Group (MOSSG) to elaborate a complete work plan and prioritize the work to be done.

In either case, harmonization of views and complete coverage of the domain are a real challenge for the IOAG agencies in the upcoming years.

Navigation:

The IOAG established a Liaison with the ICG in 2011. The primary architecture objective is to define a Space Service Volume for spacecraft navigation support from GPS, Galileo, Compass, Glonass and other GNSS systems. This space service volume is critical for navigation of many near Earth spacecraft. This being a new liaison and a new challenge for the IOAG, only an inventory of requirements was initiated in IOAG with a synthesis and first results expected in 2013.

8 – Conclusion

The IOAG is currently preparing the third IOP to be held around mid-2013. This meeting will be the occasion for a presentation and validation of the work accomplished after the IOP-2. The expected outcomes are to establish commitments on some of the IOAG recommendations and to get new guidance on the work to be made in the next years to come.

The preliminary roadmaps that will be establish at the IOP-3 will cover the following matters:

- consolidation of the architectures required for the cross supports in the new domains of interoperability, as identified in the present paper (Space Internetworking, Mission Operations, Optical Links) ;
- identification of candidate target missions and definition of the milestones to meet the objectives of implementing the recommended architectures and their associated standards ;
- identification of opportunities for in-flight demonstration of the utilization of the new standards.

[ix] **"Results of the Optical Link Study Group"** – Space Ops 2012 - Authors: John Rush, Klaus-Juergen Schulz

The progress made in the preparation of the IOP-3, through the upcoming IOAG meetings in 2012 and early 2013, as well as the resolutions that will be formulated after IOP-3 by the senior management of the Member Agencies, will be public information on the IOAG web site as will become available after each meeting.

To remain updated on the progress of this activity, do not hesitate to visit the IOAG web site at: www.IOAG.org.

Acknowledgements

The Authors acknowledge the work conducted in the IOAG by the Member Agencies represented by: Luca Salotti ASI ; Jean-Marc Soula CNES ; Martin Pilgram DLR ; Michael Schmidt ESA; S. K. Shivakumar ISRO; Hiroshi Inoue JAXA ; Philip Liebrecht NASA; Victor Ashurkov RFSA ; Peter Allan UKSA ; Sangil Ahn KARI