FOURTH INTEROPERABILITY PLENARY

IOP-4 General Forum Meeting Minutes

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IOP-4 Meeting Minutes
Oberpfaffenhofen, Germany
19-20 December 2018

Attendance:
Chair: Michael Schmidt
Secretariat: Barbara Adde, Madeleine Bronstein

Members:
ASI: Fabio D'Amico
CNES: Frederic Pradeilles, Jean-Marc Soula
CSA (teleconference): François Alain, Réal Palardy
DLR: Felix Huber, Martin Pilgram, Rolf Kozlowski
ESA: Gian Paolo Calzolari, Ian Harrison, Klaus-Juergen Schulz, Rolf Densing
JAXA: Hirokazu Hoshino, Kazuo Tachi, Shinji Ogawa, Tsutomu Shigeta
NASA: Badri Younes, Cathy Barclay*, Dan Smith*, David Israel*, Greg Mann, Philip Baldwin*, Phil Liebrecht, Wallace Tai

Observers:
CNSA: Gan Yong
KARI: Hyo-Suk Lim, Sangil Ahn
Roscosmos: Gudnov Vasiliy, Gulyaev Ivan
SANSA: No representative(s) present
UAESA: Adnan Alrais
UKSA: Matthew Cosby, Tony Forsythe

Liaisons:
CCSDS: James Afarin
ICG: James J. Miller*, Werner Enderle*
ISECG: No representative(s) present
SFCG: Enrico Vassallo

*Participated via teleconference

Presentations are available at: www.interoperabilityplenary.org.

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Introduction: Chairman

The Chairman welcomed the delegates to the IOP. He provided an overview of the agenda and asked the delegates to introduce themselves. After delegate introductions, the Chairman provided an overview of the IOAG.

IOAG Overview: Chairman

IOP Role and Expectations

The Chairman reminded the delegates of the IOP's scope, including providing guidance for interagency interoperability to enable cross support and facilitating communication and mission operations for future complex space systems. The IOAG's expectations from the IOP are to acknowledge achievements of the IOAG regarding the previous IOP related resolutions, acknowledge and endorse or amend the role of the IOAG, acknowledge and provide guidance (as relevant) regarding the future plans for cross support defined by the IOAG, and to act as a forum at the leadership level for discussion between agencies regarding operations related issues relevant to cross support.

IOAG Specific Priority Items

The Chairman identified the IOAG's top priority items that influence the technical work of the IOAG working groups and the interactions with the various liaisons. The IOAG identified the following items as priorities: protection of critical frequency bands for space research and earth-exploration satellites, enabling high data rate communications, promoting utilization of the 26 GHz band for Low Earth Orbit (LEO) missions, define critical IOAG services relevant to cross-support and interoperability, facilitating spacecraft emergency cross-support, and facilitating navigation interoperability for space operations. In addition, the IOAG recognized support to future exploration programs, facilitating space internetworking, and the preparation of mission operations interoperability services as priorities. Further details may be found in the associated document.

IOAG Relations with International Bodies

The IOAG maintains relationships with the Consultative Committee for Space Data Systems (CCSDS), International Committee on Global Navigation Satellite Systems (ICG), International Space Exploration Coordination Group (ISECG), and Space Frequency Coordination Group (SFCG). It provides guidance, operations drivers, and requirements to CCSDS regarding the development of required standards; exchanges information and supports the coordination of activities with the ICG; provides guidance and support regarding the definition and

implementation of communications infrastructure with the ISECG; and exchanges information on the need for new spectrum allocations and priorities for defending existing allocations by maintain mission model data with the SFCG.

IOAG Working Groups

The Chairman provided an overview of the IOAG working groups and their contributions to the IOAG. Further details on these descriptions may be found in the associated document.

IOP-3 Resolutions Summary for International Bodies

The IOP-3 acknowledged the relevance of the cooperation between international bodies and agreed to maintain a close cooperation with international bodies, in particular CCSDS (regarding standardization activities relevant to cross support), ICG (regarding the coordination of Global Navigation Satellite Systems (GNSS) space user performance needs), ISECG (regarding communication aspects of the Exploration Program), and SFCG (regarding standardization and protection of valuable frequency bands).

IOP-3 Resolutions Summary for Working Groups

The Chairman presented the resolutions summaries of the LEO26WG, MOSCG, OLSG, and SISG following the IOP-3. Further details on these resolutions may be found in the associated document.

IOAG Achievements since IOP-3

Since IOP-3, the IOAG has successfully exchanged information between agencies about technology demonstrations and ground station evolution, increased cross support between participating agencies, executed test cases regarding the spacecraft emergency initiative, maintained IOAG products (including models, the communications assets database, and others), updated the service catalogues, and provided technical reports from various working groups. It has also updated the definition of the priorities for specific topics, kicked off several new working groups (i.e. CMWG, LMWG, LCAWG, MOSSG, and SECSWG), defined an interoperable lunar communications and navigation architecture, and achieved all SFCG goals at ITU WRC-15.

Achievements of IOAG in Promoting Cross Support

The Chairman emphasized that cross-support activities among space agencies have been increasing and more new agencies are participating in cross support. He furthered that it is important in the IOAG to identify the infrastructure necessary to build this cross support. The outputs of the working groups are helping in defining the support and necessary interoperable communication architecture. An example of this is the LCAWG for future Lunar missions.

IOAG Future Evolution and IOP Guidance

The IOP was asked to provide guidance regarding the potential evolution and ongoing work of the IOAG including closure of existing or establishment of new working groups. The IOAG asked the

IOP to endorse the role of the IOAG in the context of the future exploration activities and to act as the coordinator of the communications infrastructure (e.g. recommendation for a communication architecture including standards and frequencies in the future exploration program). The IOAG also asked the IOP to identify tasks related to topics addressed during the Leadership Forum.

The associated document for this presentation may be found at: https://www.interoperabilityplenary.org/Interoperability%20Documents/IOAG%20Presentation%20141118.pptx?d=w6aeddf691843452699a07733026aa970.

ISECG Report: Presented by the Chairman

The Chairman presented a report on ISECG activities on behalf of the ISECG liaison. The ISECG is a group that was formed from various agencies' space station activities working together to define upcoming global exploration, reflected in the Global Exploration Roadmap. The GER defines the future of human exploration, however, it is important to emphasize that the Roadmap is not a commitment on behalf of the agencies and participants, but a tool to maintain as a reference. The space agencies participating in the ISECG will continue the dialogue with stakeholders to coordinate and advance sustainable space exploration, extending human and robotic presence in the Solar System.

The ISECG has had ongoing cooperation with the IOAG to work towards consistent assumptions and coordination through providing a status of their work at IOAG teleconferences. The IOAG has also given status presentations at appropriate ISECG meetings. The important measure of progress for this cooperation is for interoperable communication standards for ISECG to be consistent with IOAG standards. This ensures that communications infrastructure remains compatible with both science and exploration space vehicles and that the community leverages the work of both without unnecessary duplication of effort. Standards were provided to the IOAG for review and comment in addition to there being involvement of IOAG representatives in agency efforts to develop draft standards. The powerful result of this coordination was that an International Communications Interface Standard, compatible with the IOAG Lunar Communications Architecture will be baselined in early 2019 by the ISS Multilateral Control Board.

The Chairman presented the proposed resolutions to be discussed and reviewed for the communique. The delegates had no comments to Resolution #1 or Resolution #2. In response to Resolution #3, the delegates noted that since the communications architecture has not been finalized they will take note of the recommendation and discuss approval of it in the future. In response to Resolution #4, Mr. Younes noted that there are already many activities for Mars and some are critical communications needs. There is currently a shortage in capacity available and he is not sure which other agencies are looking into this to support missions in the immediate future (2020-25 timeframe). Mr. Younes asked if the resolution refers to human exploration of Mars,

which is a different topic. Mr. Schulz responded the idea was based on recognition of a positive outcome of the Lunar Communication Architecture and that we would need to have a similar architecture for Mars guided by the lunar architecture. Mr. Younes suggested adding "evolving" architecture for Mars-related activities, because deep space is different for proximity operations and requires more automation.

The Chairman asked for any further comments on the ISECG presentation. Mr. Soula asked which group the standards have been coordinated with. Mr. Liebrecht responded that it has been coordinated with the LCAWG. Mr. Soula asked if it is architecture or standards related. Mr. Tai responded that the ISECG accepted the LCAWG's input to them on an international standard for lunar exploration. Mr. Liebrecht added that there is a broader set of standards developed by the ISS group that relates to other compatibility needs, but the communications and navigation standard is the standard that has been worked with the IOAG and is consistent.

CCSDS Report: Presented by James Afarin

Dr. Afarin presented an overview of the founding, purpose, and observer and member agencies of CCSDS. It is currently developing 80 data standards in 6 technical areas by 23 teams. These are technology development projects that are created, funded, and executed internationally. To date, 1,111 space missions have adopted and used various CCSDS standards and there are currently 154 active publications with approximately 370 publications since 1982.

Dr. Afarin listed future mission drivers for in situ exploration, complex deep space missions, orbital remote sensing, and next generation observatories. Since IOP-3 in 2013, CCSDS standards have played a key role in facilitating on-going international collaborations for future missions. He noted that it is important for agencies because it crosses geopolitical boundaries and has been highlighted as an example of international collaboration. Looking into the future, a number of new standards, recently developed or still in development, will advance space communications into a new area, benefiting the space missions at an unprecedented scale. Among them are optical communication standards for extreme high-rate links, DTN standards for space internet, USLP for advanced data communications, high-performance coding for high-rate forward and proximity links, navigation and mission operations standards for spacecraft control, and service management and cross support service standards for interoperable multi-agency cross support. Dr. Afarin provided an overview of these standards and noted that the mentioned CCSDS standards will lead the IOAG member agencies to realize a new space communications architecture in a new era as illustrated by the three planetary networks.

The Chairman asked if there were any inconsistencies or problems with mission plans on the Mars planetary network. Mr. Cosby responded that they received input from agency missions to inform the architectures, so it should be consistent for the lunar architecture. The Chairman asked what percentage of the scenarios was done by the working group. Dr. Afarin replied that some of the

USLPs and DTN capability still has to be developed, so about 80% has been done. Mr. Tai noted that there are still some things that haven't been touched upon by CCSDS, for example, multiple access standards. The Chairman asked Dr. Afarin what CCSDS's plans are for finalizing outstanding standards. Dr. Afarin responded that there are priorities, but there are limits to what can be done with current funding. The Chairman noted that he would like to see which activities are required and the expected work from the IOAG for input to CCSDS. Mr. Soula responded that the IOAG and CCSDS needs to make sure there are no major gaps and the groups should meet more frequently to ensure cooperation. Mr. Liebrecht added that mission models need to be kept up to date. The IOAG work is highly dependent on the needs of those science and exploration missions.

Dr. Afarin provided an overview of CCSDS's resolutions. Referencing Resolution #2, Mr. Younes asked what was meant by "strategically stage interoperable capabilities." Dr. Afarin clarified that this refers to strategically having interoperability supported. This is not for specific missions or agencies, but strategically endorsing interoperability for moving forward. Mr. Schulz added that when compiling the lunar communication architecture, the working group had standards at hand to realize the architecture. What is needed now is standards onboard technical systems. Currently, only the high data rate uplink is missing. The strategical aspect is that we have all technical standards at hand. Mr. Younes noted that he has no problem with strategically doing standards, not capabilities. Mr. Liebrecht proposed rewording the resolution to read: "The IOP supports the CCSDS to continue their work to strategically stage interoperable standards for the next generation of spaceflight missions."

ICG Report: Presented by James J. Miller and Dr. Werner Enderle

Mr. Miller and Dr. Enderle thanked for the Chairman for the opportunity to participate in the IOAG and noted that the relationship has been very beneficial. Mr. Miller provided an overview of the ICG's founding, members and associate members, observers, and annual meetings. The ICG's primary objective is to ensure compatibility and interoperability between Global Navigation Satellite Systems and regional systems. Today, this interoperability focuses on the Space Service Volume, which is currently from the surface of the Earth to GEO. One of the objectives of NASA's participation in the ICG is to expand the volume of GPS and GNSS availability in space.

There are many space uses of GNSS and it is becoming standard equipment for space platforms. Uses include real-time on-board navigation, attitude determination, earth sciences, and launch vehicle range operations. The capabilities of individual GNSS to support space users is further improved by pursuing compatibility and interoperability among the various GNSS. Because of these uses, NASA holds an interest in how GPS is modernized and participates in the PNT Executive Committee.

The IOAG and ICG collaborates to capture missions investing in GNSS through a GNSS Space User Database. The ICG encourages providers, agencies, and research organizations to publish the details of GNSS space users and contribute to the database, which is updated annually as missions are planned. The database has been very useful to the ICG in understanding the extent of GNSS use in space and developing recommendations to pursue interoperability, in particular for users in HEO. The results show the high level of GNSS equipage investments coming online. Mr. Miller explained the use of GPS and GNSS in HEO and noted that it is still being understood how far out the signals can be processed. He noted that the key objective of multi-GNSS analyses is to demonstrate and quantify improvements in signal availability by using interoperable, multi-GNSS receivers within the SSV.

In addition, Mr. Miller noted that outreach initiatives are a key enabler for technical exchange, consensus, and action. Current and past initiatives include the SSV booklet, which documents and publishes SSV performance metrics for each individual constellation, includes internationally coordinated multi-GNSS SSV analyses and simulations, communicates assumptions and analysis results, supports international space user characterization of PNT performance in the SSV, and was formally released at ICG-13; an SSV outreach video currently being finalized by NASA on behalf of the ICG; and coordinated outreach to communicate the capabilities of the SSV to future space users.

Mr. Miller also outlined the growing promise of GNSS for navigation in the SSV and beyond. Benefits include enabling continuous navigation capability, significantly improving navigation performance, supporting increased satellite autonomy and lowering mission operations costs, supporting quick trajectory maneuver recovery, and enabling new and enhanced capabilities and better performance for missions such as: earth weather prediction using advanced weather satellites, space weather observations, precise relative positioning, precise position knowledge and control at GEO, formation flying, space situational awareness, proximity operations, and those beyond GEO and Cislunar space.

The IOAG's engagement with the UN ICG is contributing towards the pursuit of interoperability among the various GNSS constellations in support of space users. Through the UN ICG, all GNSS constellation service providers have adopted a common definition for the multi-GNSS SSV, published performance characteristics, and performed joint analysis documenting the benefits of utilizing multi-GNSS in this regime. The benefits of enabling greater signal availability are now well documented. To continue this, GNSS service providers, supported by space agencies and research institutions, and encouraged to support the SSV in future generations of satellites, measure and publish GNSS antenna gain patterns, and share SSV user experiences and lessons learned. Mr. Miller furthered that the increase in performance enables numerous benefits across a range of user applications and is intended to foster expansion in technology development and application of high-altitude GNSS. This enables and promotes civil and commercial space access and markets. Mr. Miller concluded by noting that the SSV will evolve through the ICG community to meet user needs and user engagement and feedback is needed to maximize value and utility.

Mr. Miller provided an overview of the resolutions and the delegates had no questions on or changes to the resolutions. The Chairman thanked Mr. Miller and Dr. Enderle for the presentation and the SSV Booklets provided to the IOP attendees.

SFCG Report: Presented by Enrico Vassallo

Mr. Vassallo noted that the SFCG and IOAG have been cooperating for many years on frequency management issues for which high-level visibility is needed. Primary activities in the past included discussions on the future of the 2 GHz bands, the frequency bands to be used for Lunar and Martian missions, the application of SFCG recommendations to cross support of non-SFCG members, and the defense of the many bands under attack at the ITU WRC-15. There have been many important accomplishments achieved by the SFCG thanks to cooperation with the IOAG. The cooperation work between the SFCG and IOAG after the IOP-3 has been focused on the ITU WRC-19.

The main WRC-19 agenda items of concern and interest to the IOAG member agencies include AI 1.13 (IMT-2020), 1.14 (HAPS), and 1.16 (RLAN), as well as AI 1.2 (400 MHz limits), 1.3 (460 MHz upgrading), and 1.7 (short duration missions). The goal is to obtain the same level of success that was achieved at WRC-15. Mr. Vassallo provided an overview of each of the agenda items which may be found in the associated document. Referencing AI 1.16, Mr. Younes asked who is pushing for 5 GHz. Mr. Vassallo responded that the UK and U.S. are.

The proposed way forward is for the IOP-4 to inform Member Agencies' frequency managers about the progress of WRC-19 agenda items that are critical to IOP-4. In addition, ESA/NASA results on AI 1.13 station coordination and the different assumptions used by China, Brazil, and Korea leading to no coordination requirements have to be explained; the ITU-R recommendation on proposed methodology for earth stations protection (coordination zones) has to be supported to have the same approach all over the world; the draft CPM text proposing a review of IMT-2020 parameters during deployment, conditions for earth station coordination and licensing, and sensor protections, inter alia, has to be supported; and the protection of on-board sensors from unwanted emission of IMT-2020 has to be guaranteed via IMT-2020 emission limits (levels proposed by CEPT can not be further relaxed).

Mr. Vassallo reviewed the proposed resolutions. Mr. Younes asked whether there is support from all SFCG members on Resolution #2(i)? Mr. Vassallo responded positively. Referencing Resolution #2(ii) Mr. Younes asked if aggregate power flux density was considered. Mr. Vassallo replied that this should be considered in the future, but not for the time being. Mr. Younes noted that NASA has been doing these things already and supports the resolution. He urged the other agencies to support it as well.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/SFCG%20report%20to%20IOP-4v3.pptx?d=w2571512e60f84e549e5e2ff5e6499acb

Evolution of Communications: Presented by Jean-Marc Soula and Phil Liebrecht

Mr. Soula and Mr. Liebrecht presented the top level global space agency needs for future missions: safe, secure, and efficient interoperable mission operations; higher rate throughput for science and exploration missions; and responsive networks around the Earth, Moon, and Mars to enable future exploration and science missions.

An aspect of safe, secure, and efficient interoperable mission operations and cross support is backup and emergency cross support. This includes standards for TT&C, SOPs for spacecraft emergency cross support, and lower frequencies (S- and X-bands) to acquire and track disadvantaged users using omni or low gain antennas with uncertain orbits and/or attitudes. Other aspects include continuing to utilize S- and X-bands; interoperable standards as missions with international partners become the norm; robust PNT; and interoperable space positioning, navigation, and timing capabilities as STM becomes more challenging, missions move farther into the Solar System and beyond, and approach and landing on planets and asteroids becomes more common. Another aspect is protecting spectrum to accomplish tracking (L, S, and X bands). Mr. Soula and Mr. Liebrecht also identified the importance of security for space missions, including implementing mission operations and security standards and services for international partner mission communications and operations.

The goal to enable higher rate throughput for science and exploration missions is a result of exploration beyond LEO (e.g. Gateway and eventually Mars) requiring increased bi-directional data and future science missions (e.g. NISAR, PACE, JWST, WFIRST in near Earth space, and future Mars exploration reconnaissance) generating orders of magnitude more data. Because of these factors, missions need interoperable Ka-band forward and return services, optical communications services, efficient coding and modulation, and space internetworking with IP/DTN. In addition, Ka-band spectrum must be defended.

Mr. Soula and Mr. Liebrecht noted that in order to implement networks around the Earth, Moon, and Mars to enable future exploration and science missions and activities, such as human and robotic joint mission operations (e.g. coordinated Gateway, landers, rovers, hoppers and coordinated astronauts and robots) and sample return from planets (requiring landers, launchers, and rendezvous in orbit), agencies need PNT for planetary surfaces and systems, robust coverage for surface planetary systems, and increased communications forward and return directions. They recommended adopting the Lunar Communications and Navigation Architecture, evolving the Mars Communications and Navigation Architecture, and implementing space internetworking.

To summarize, Mr. Soula and Mr. Liebrecht emphasized that to enable future missions, global space operations architecture requires: continued use of robust TT&C and PNT capabilities, new Ka-band and optical links to increase data throughput, space internetworking to allow multiple robots and humans to work together, and standards to securely facilitate mission operations centers

collaboration. It is important that the aforementioned architecture is internationally interoperable. In addition, necessary spectrum, including L (PNT), S, X, and Ka-bands, must be defended.

Mr. Schulz noted that techniques have to be developed to communicate at distances closer to the sun. If missions move to Ka-band for TT&C, then they can move closer to the sun, leading to higher productivity of those types of missions. This may also influence the future architecture for interplanetary communications behind the sun. Mr. Liebrecht agreed that this could be a possible capability implemented first by Mars missions.

Review of Leadership Forum

The Future Role of Agencies

The Chairman reviewed discussion on the topic of the future role of agencies. He reiterated that many delegates suggested that the IOAG act as a bridge to industry while others noted that there is still differentiation between the roles of industry and government. While industry caters to repetitive missions, government institutions support one-of-a-kind missions. The UKSA proposed utilizing the next IOAG to hold a meeting with industry. Mr. Cosby noted that based on the Leadership Forum discussion, UKSA is prepared to invite industry for presentations and discussion as part of the IOAG. However, there is also a blurring of institutional and commercial relating to exploration, so further information needs to be gathered and the UKSA can assist with a proposal for this.

Mr. Schulz noted that the conversation with industry should be done in a fair manner with equal treatment. He asked Mr. Cosby if the IOAG would be picking individual companies out to interact with. Mr. Cosby responded that they will work on a proposal and the IOAG can work on how to fairly conduct the meeting. The meeting should not be too broad, but should also be done fairly. Mr. Soula added that he supports inviting industry for a discussion, but the objective of the workshop should be clearly outlined ahead of time. There is interest related to the Moon and exploration, but there needs to be a narrower focus on which type of "industry" and which topic the IOAG is addressing. Does the IOAG promote cooperation and cross support with industry? If the discussion is on standards, the IOAG should invite providers of services, because they have a better understanding of differences between government and industry. The IOAG should form questions to ask regarding what should be addressed.

The Chairman took the delegates' comments into account and proposed circulating UKSA's proposal and discussing it at an IOAG meeting. He added that Mr. Soula and Mr. Alrais had also mentioned engaging with academia and New Space. The IOAG should address communication with these groups as well and see if cooperation should be considered. The IOAG has a tendency to discuss technological issues, but it should be determined whether political and regulation issues should be addressed in the forum, or if the discussion should stay on the technical side. Mr. Liebrecht noted that during SpaceOps 2010, a paper was presented by Mr. Soula and a commercial

supplier inquired about joining the IOAG, so there is demonstrated interest on the commercial side going back at least that far in time.

Future Trends and the Evolution of Agencies

The Chairman noted that the delegates first discussed efficiency with operating satellites. In addition to automation, new technologies include responsive technology and artificial intelligence. This topic is relevant to all IOP agencies and all agencies should be involved in discussing new technologies. Other technologies mentioned by Mr. Younes during the forum included optical, quantum, and cognitive communications. Mr. Younes noted the importance of these technologies and that NASA is trying to push technology that allows the benefit of optical communications in terms of increasing the capacity available to support users and also allows NASA to operate in the business space. The key technology NASA is going after will not be burdened by existing regulations for spectrum and allows reconfiguration of capabilities in real time to allow the user flexibility to acquire the support they need. Cognitive will allow NASA to make decisions at the network level and efficient communication pathways. Optical will give us at a minimum an order of magnitude better performance and a larger capacity. The future will rest on the quantum domain and quantum networking. However, before those technologies can be implemented, optical networks have to be implemented. Identifying interfaces and building the hooks necessary for capabilities to transition smoothly into quantum once optical networks have been implemented is essential. NASA sees this for the 2025-2027 timeframe. Mr. Younes also clarified that he is referring to quantum technology (quantum computing, networking, memory, etc.) and not quantum key distribution.

Other important technologies addressed by the delegates included how to address the topic of security systems in the IOAG as well as technologies in the context of Lunar and Mars exploration, including those for long distance data transfer, proximity operations, and rendezvous.

Space Traffic Management

Mr. Soula recommended that the first step be to coordinate on gathering information for current activities on STM. If any activity is started in the IOAG on this topic, the outcome of the work may be to identify what is not currently properly addressed and to come up with recommendations. The IOP has only heard from a few agencies on this topic, so the IOAG should gather the views of other agencies on their interest in addressing this topic in the IOAG.

C&MWG Report: Presented by Gian Paolo Calzolari

Mr. Calzolari first provided an overview of the C&MWG membership. He stated the problem the working group addressed is that CCSDS standards have successfully allowed a new era of international space exploration and cross support, however, during the years the number of coding and modulation schemes available in those standards has grown significantly. Currently, the expectation is all core standards in the IOAG service catalog should be implemented at applicable

participating ground stations, but this approach would require a large investment by agencies. Moreover, there is currently no incentive, beyond their superior performance, to use newer, better standards.

The C&MWG was chartered by the IOAG at the IOAG-18 meeting as a focused sub-team to identify a subset of preferred modulation and coding that pertain to core standards. It has surveyed IOAG member agencies to see which standards are being used today or planned for the future, analyzed the results to identify standards that are most likely to be used in the future, and developed a preferred list of core standards for coding and modulation.

The IOAG C&MWG encourages missions seeking cross-support services to choose coding and modulations from the preferred list such that ground stations by member agencies should become capable of supporting the applicable standards from the preferred list. This does not place any restrictions on missions using any other standards (or proprietary) codes or modulations, as long as they do not expect to receive international cross-support standard services.

Mr. Calzolari recapped the results of the working group, including that "Recommendations on Preferred Coding and Modulation Schemes" were approved at IOAG-19d in April 2016, and consequently, the SCWG has updated the IOAG Service Catalogs to refer to the Report, the IOAG informed CCSDS about the preferred list, and the IOAG encouraged adherence to the Preferred list for missions requiring international cross support services. A summary of the likely reductions in standards used by new missions can be found in the associated document.

Mr. Calzolari addressed the future of the working group based on discussions at IOAG-22a in June 2018. The C&MWG will periodically review the CCSDS list of coding and modulation standards, consider reviewing the report (when appropriate) and possibly add new membership to reflect actual IOAG participation and changes, and update (when required) the list of preferred standards. He noted that the group expects approximately a 5-year cycle for the updates. Mr. Liebrecht asked how the 5-year timeframe was determined. Mr. Calzolari responded that this was decided on as the reasonable timeframe for refreshing or confirming documents, but clarified that it is a minimum of five years and the documents can be refreshed before then if necessary. The Chairman concluded the presentation by noting that there is no need for resolutions for this working group.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/IOP4%20CMWG%20Report%20v2.pptx?d=w582410fbe3ed4ed6a99dfb208a3b7b8e

SECSWG Report: Presented by Catherine Barclay

Ms. Barclay presented an executive summary of the SECSWG and noted that she had replaced Jon Walker as the chair of the working group. The SECSWG was formulated based on action from the IOP-3 to assess options for emergency cross support for interoperability. Its achievements to date

include completing the initial draft of the SOP and conducting proof of concept demonstrations for a non-registered mission scenario, which was used to define data exchanged between service providers and users. Ms. Barclay outlined the key considerations for implementing emergency cross support, including RF licensing and interagency agreements. She presented the proposed future work of the group to complete validation and establish the SOP, continue exploring options to reduce response time for SECS, explore options for establishing ground communication lines infrastructure, and explore options for engaging commercial providers for emergency cross support. She also noted that the working group has had very active participation and is working effectively as a cooperative multi-agency effort.

These emergency cross support services are intended for cases in which a spacecraft is in distress and nominal and backup service providers are not capable of providing the needed emergency services to save the spacecraft. In these scenarios, time is critical and requesting cross support from a non-registered service provider can often be a lengthy process. The authorization of service provision and configuration of the respective ground station requires a significant level of effort and time. In response to these factors, the IOAG has focused on identifying opportunities to reduce a service provider's response time and streamline the interagency coordination process. It has also developed a generic standard operating process for acquiring SECS services, which considers technical, regulatory, and resource constraints as well as acts as an efficient approach that could significantly reduce a service provider's ground station preparation time. She explained that standard TT&C services are often what is required for support, but other types of engineering support may include analysis on the downlink or uplink. The idea is that data would be collected on ground station capabilities so that stations may be called up for a specific type of needed support. There are also various levels of preplanning, including registered and nonregistered entities.

Ms. Barclay presented a visual for the implementation of SECS services and a chart outlining the purpose and IOAG approach to various strategies to reduce response time. The strategies identified include defining a standard spacecraft specification template, identifying an agency point of contact to initiate the provision of SECS services, forming an accessible ground station parameter table, conducting coordination with service providers, and acquiring an RF license. Further details on the services visual and purpose and approach to strategies can be found in the associated document.

Further details on the achievements of the working group include that it was verified that emergency cross support does not require any new services. All services required to support emergencies are either listed in the current IOAG service catalog or are available at the ground stations. In addition, included in the SOP are key emergency services including engineering and forward/return data delivery services, each agency's points of contact to request SECS, a standardized spacecraft-service provider interface specification, and the ground stations that could potentially provide SECS, along with their respective technical and regulatory constraints. The SOP also includes recommendations on preventative measures that could significantly reduce a

service provider's response time, such as early coordination with service providers. Ms. Barclay also provided details on the conducted demonstrations. In early 2018, the IOAG conducted proof-of-concept demonstrations proving that a service provider is able to configure a ground station and adequately provide SECS services with minimal pre-coordination and testing. Examples of this include ESA tracking Hayabusa-2 and JAXA search-tracking JASON-3, verifying the engineering service. In 2019, the IOAG is planning additional service demonstrations to refine and validate the draft SOP. The IOAG expects to complete validation of the SOP in 2019.

Ms. Barclay noted the key considerations for service implementation: RF licensing regulations and interagency agreements. Pertaining to RF licensing, during an emergency, a service provider may be requested to provide SECS services using a ground station that does not have the appropriate RF license. ITU Radio Regulation paragraph 4.9 enables ground stations to radiate without a license under these circumstances without violating these international regulations. However, while many countries' domestic regulations reflect an analogous sentiment for emergency cases, certain ground stations may be subject to more stringent domestic regulations, inhibiting them from providing the full suite of SECS services. She noted that such domestic regulations have been documented in the SOP. The working group has been in contact with Mr. Vassallo regarding ways to move forward on this effort. Mr. Younes asked which countries did or did not sign off on ITU Reg. 4.9. Ms. Barclay said she does not currently have that information.

Regarding interagency agreements, Ms. Barclay explained that the problem this solves is that the time needed for a service provider to respond to a request for SECS, particularly for cases with no existing mission-level or agency-level agreement, may potentially increase due to internal agency and country review as well as the authorization process. Therefore, the IOAG surveyed its member agencies regarding their preferred interagency agreement approach for spacecraft emergency cross support management. Initial conclusions from the survey suggest that there are multiple methods of establishing support agreements in order to accommodate each agency's preferred approach. These methods may include establishing an IOAG policy statement between all participating agencies, establishing general or mission-specific bilateral agreements, or establishing a multilateral agreement between all participating agencies. The full list of methods preferred by each agency may be found in the backup slides of the associated document. The IOAG plans to establish a policy statement for these services and for cases where the policy statement is not sufficient, interagency agreements may need to be established to enable these services.

Ms. Barclay then reviewed the recommended resolutions for delegate feedback. Referencing Resolution #2, Mr. Liebrecht recommended rewording the resolution to emphasize that emergency support should not be called on as a substitute for backup support and that agencies should do proper mission planning including risk assessment and identifying backup support options. Ms. Barclay responded that she would reword the resolution for the final communique.

Referencing Resolution #4, the Chairman asked the delegates if expanding the SECSWG scope to consider emergency cross support services for manned exploration missions and to explore

opportunities for engaging commercial providers should be done. Mr. Younes responded that he believes it is worth looking into as commercial providers become more capable. In the case of an emergency, a mission would want to use all available resources to recover the spacecraft. Ms. Barclay added that as the group expands to address human missions, there are differences in priorities associated with human and robotic missions, so this would add a new meaning to the types of emergencies. For example, the PPE is trying to engage with the working group and pull emergency services into their plan. In addition, commercial providers have expressed interest on an informal level by sharing standard formats and inviting the working groups to meetings. The Chairman asked Ms. Barclay to clarify the kind of services that would be addressed. Ms. Barclay responded that TT&C services and engineering services are being addressed. If there is a desire for a specialized service, the idea is that this would fall under requesting other engineering services. The Chairman noted that the commercial aspect of this could be a potential topic for the proposed IOAG-23 industry day.

For Resolution #5, Mr. Younes emphasized that the language should reflect the ability of individual agencies to form bilateral or multilateral agreements by themselves. Mr. Soula added that there was discussion within the IOAG on more or less binding agreements, but if this should not be a part of the work of the group then the group may establish a policy statement and leave the agreements as a responsibility of the agencies. Mr. Younes responded that NASA supports the concept of encouraging space agencies to pursue such agreements, but they must be decided individually. Ms. Barclay noted that she would reword the resolution for the final communique.

It was asked if an agency could request support without an agreement in place. Ms. Barclay clarified that this would be classified as a non-registered mission and support would be attempted, but it would take longer without prior approval. Mr. Liebrecht added that there are many more steps in the process for providing or obtaining support if there is not an agreement in place and that is why there should be an agreement up front. Mr. Younes noted that whether there is an agreement in place or not, NASA views emergency support as a high priority, especially in the case of saving human life or a mission. Mr. Soula reiterated that the talking point of the working group is the situation that was just described. There is a long lead time for emergency support and the group has been trying to identify which steps are needed to reduce the response time. Mr. Huber agreed that the IOP should encourage agencies to follow procedures. Mr. Soula offered that steps have to be defined for the procedures and information gathered on ground stations and satellites, so the first improvement for this process is to prepare that. There are costs involved for this and that is why there is another step, which is the committed case. The question was what kind of agreements can be established within the IOAG, but because of the different agency responses, the group would like to go further and prepare a procedure or policy within the IOAG about what can be done. He agreed with Mr. Younes' comment that the IOAG should not commit the space agencies to a certain agreement and only put the processes and capabilities in place to provide emergency support. Ms. Barclay agreed that the intent of the second part of the resolution was not to mandate agreements, but to suggest that they may be a good idea to reduce lead time. She noted

that she would reword the second part of the resolution to reflect the delegates' feedback for the final communique.

Lastly, Ms. Barclay provided further detail on the group's future work. This includes: baselining the SOP for robotic missions and exploring the expansion of the working group scope to include manned exploration missions, continuing to investigate key issues pertaining to the implementation of SECS services and working towards establishing a common approach for resolving these issues, exploring options regarding implementing ground communication line infrastructure that may be utilized during emergency cross support scenarios, researching opportunities to engage commercial service providers in emergency cross support activities, and documenting an IOAG policy for managing emergency cross support services.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/IOP-4%20SECSWG%20Presentation%20Exec%20Summary%20v9.pptx?d=w991303f62ba24d0f9d95a7e77e402c3e

LEO26WG Report: Presented by Philip Baldwin

Mr. Baldwin presented the background, purpose, and scope of the working group. The LEO26WG was initiated in 2012 as a response to X-band congestion and a continued growth in the number of missions and providers using the 26 GHz band necessitated by a growing need for higher data rates to support missions. The purpose of the working group is to facilitate the utilization of the 26 GHz K-band direct space-to-Earth data downlink for future LEO missions in the context of cross support, develop a high-level Concept of Operations and preliminary architecture inputs for a 26 GHz K-band system for LEO, and determine the business case for cross support at 26 GHz for LEO applications.

Achievements of the working group include the LEO26GHz Report which was initially published in 2013 and first updated in 2016. It was most recently updated in 2018 to include additional information from lessons learned analysis. In this analysis, the group observed expected benefits of 26 GHz usage, created a checklist for missions considering the 26 GHz band, determined that there is a need for additional ground stations and more equipment vendors, found operational coordination helpful, and concluded that the propagation analyses were valuable. Mr. Baldwin also provided details on the launched mission observations for JPSS-1, TESS, and others. Further details on these may be found in the associated document.

The path forward for the group is to monitor progress on the use of the 26 GHz band, ensure spectrum is defended, promote the use of ACM/VCM and include ACM/VCM as an option for future Ka-band missions by sharing findings with mission planning entities, continue atmospheric studies to collect data over multi-year periods, and expand the scope of the working group to

initiate support to missions of both large and small satellite types in all orbit regimes from near Earth to Lagrange points.

Mr. Schulz noted that ESA does not have the intention of holding a systematic network of Ka-band stations and this service provisioning is planned to be done in the commercial domain. Mr. Baldwin responded that there will be NASA ground stations upgraded with Ka-band, but the agency will also rely on commercial partners, such as SSC and KSAT for relaying government data. Mr. Schulz asked if there is an infusion plan from the space agencies. The Chairman responded that there is not. Mr. Soula asked if CNES should include that 26 GHz is not a domain of theirs in the future and will instead rely on commercial providers. Mr. Younes noted that 26 GHz is not available for commercial purposes in the U.S. and NASA expects that Ka-band will provide for wideband needs going into the future as a result of contention for 8 GHz. There are regulatory challenges to having the allocation available to us, but NASA is going to work hard to protect the band. In the past we have encouraged users to go to this spectrum and we are about to introduce policy to mandate users to go to Ka-band to meet the needs and requirements of the agency. Mr. Beck added that there is an increasing number of missions with high data rate needs and this will be very useful in the future. Mr. Younes responded that the main driver is contention for spectrum and the second driver is the need for added capacity. X-band has its limitations. Regarding concerns about the commercial market for Ka-band, NASA has a policy to pursue commercial solutions when available. If a commercial market can provide support, NASA will not invest in it. He would like for there to be a competitive commercial market and not be stuck with a single provider. NASA believes the market will be there and when we talk about utilization of frequency, this is referring to the next 10-20 years.

Mr. Baldwin outlined the working group's resolutions and proposed that the new working group be labeled the 26 GHz Working Group (26GHzWG). The Chairman asked whether there is a mechanism in place to collect and process information that is requested in the resolutions. Mr. Schulz responded that the group has two years of measurements and a cooperation agreement has been set up with NASA to share data. What has not been set up yet is whether data is freely shared between the IOAG and member agencies. Mr. Younes added that NASA has been collecting data and the results should be of interest to the IOAG community. NASA will also continue to collect this data.

Mr. Soula noted that there a currently constellations in flight with 5-6 satellites in them operating in the 26 GHz band that have plans to expand the constellation into for example, 20 satellites. He asked if in the next phase of the working group, the IOAG should coordinate with these missions and share recommendations regarding VCM/ACM and other technologies. In this way, the missions can optimize their communication systems and the IOAG can use the data from these missions to hone the atmospheric and operations models, therefore comparing the data from the non-optimized satellites with the optimized satellites.

Regarding expanding the set of 26 GHz band ground stations, Mr. Younes said that in general, NASA uses data to determine where to put the next antenna and best location for supporting operations, but because of cost issues, NASA is stuck with current locations. NASA's infrastructure is in places to support S- and X-band and does not have the funding required to build stations elsewhere. Lastly, Mr. Younes noted that for those interested, there may be a few papers presenting findings at the Ka-band conference in 2019.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/LEO26WG%20IOP-4%20Exec%20Summary%20v10.pptx?d=wa446bc2f0fa2470d9444e71bd2520d3b

OLSG Report: Presented by Klaus-Juergen Schulz

Mr. Schulz first provided an update on work completed as a result of the OLSG's IOP-3 resolutions. At the IOP-3, the IOP recommended that the member agencies begin preparing for future cross support of space-Earth and space-space optical communications by developing interoperable standards. Mr. Schulz noted that standards are being developed and will be further elaborated on. The IOAG was also requested to provide guidance to CCSDS in the development of the required standards. Mr. Schulz noted that this was done prior to the start of the standardization by defining the scope of the standardization. In addition, the IOP urged collaboration on demonstrations and experiments that may be useful in the standardization and development of optical communications technology. In response to this resolution, various interagency demonstrations were conducted (LLCD, OPALs, and SOTA) that increased the maturity of the standardization proposals and EDRS-Sentinels laser communications terminals were validated for operation. IOP-3 Resolution #5 encouraged the IOP member agencies to share technical and operational experience with other IOAG members. As a result, theoretical knowledge, space, and ground terminal designs as well as experience from demonstrations was shared. The IOP also recommended assessing the results of upcoming technology demonstration missions to verify the feasibility of a common wavelength for a future intersatellite link in the context of a data relay system in order to facilitate interoperability. A common approach for deep space optical communications was proposed and agreed to. It was proposed that Lunar Direct-to-Earth and intersatellite links use the HPE recommendation (outlined in slides). However, for near-Earth intersatellite links of data relay systems, a common wavelength and signaling format could not be defined, which led to an agreement to prepare two High Data Rate (HDR) Orange Books.

Elaborating on optical communications international standardization work, Mr. Schulz noted that sharing optical communication ground stations or relay satellites among the international space agencies would allow the agencies to share the cost of communications infrastructure. For example, due to cloud blockage, it is critical to have multiple ground stations in use during space-to-ground optical operations to provide high availability. International cross support is currently

being worked within the IOAG and the CCSDS with the goal to develop optical communications cross support by various agencies as we have today in traditional RF communications.

The scope of the CCSDS optical communications working group includes physical, coding, and synchronization layer recommendations for the interoperability of flight and ground optical communications terminals as well as recommendations for characterizing the atmosphere channel and for the concept of operations for space-to-ground links. The working group has been investigating high data rate, HPE, and low complexity focused on optical on/off keying and preparing multiple books on optical communications. Mr. Schulz presented a visual of the recommended lunar optical communications architecture based on the CCSDS HPE recommendation and a chart of example Gateway laser communication links, which can be found in the associated document. The assumptions used were that CCSDS HPE is used for DTE and ISL, CCSDS HPE telemetry signaling is used for the forward and return link, 1550 nm channels will be used for all links, and results from the on-board Gateway technology feasibility assessment.

The conclusions for standardization outlined by the study group are that HPE for Deep Space is close to becoming a Blue Book standard subject to two prototypes, optical on/off keying (O3K) Blue Book standard for LEO DTE should be advanced quickly because there is a risk that the number of proposed solutions becomes larger, and two Orange Books for HDR are underway since no consensus for a single Blue Book could be reached. The ESA/DLR HDR Orange Book has been proposed for publication.

The conclusions for infusion outlined by the study group are that: 1) HPE will be used for NASA DSOC (onboard Psyche) and O2O and is proposed for ESA DOCS; 2) O3K variants are being implemented and demonstrated leading to proprietary onboard and ground (modem) solutions so an international standard needs to be defined quickly; and 3) the ESA/DLR 1064 nm HDR Orange Book was implemented on EDRS and Sentinels. In addition, the NASA/JAXA/NICT/CNES 1550 nm HDR Orange Book will be implemented on NASA's 2025 relay. Rather than using HPE for Direct-to-Earth and both HDR Orange Books for LOP-G intersatellite links, NASA and ESA now propose to use HPE for both Lunar Direct-to-Earth and intersatellite links.

Lastly, Mr. Schulz presented the study group's proposed resolutions, which can be found in further detail in the associated document.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/IOAG%20Optical%20Communications%20Presentation%20-%20June%202018%20draft%205.pptx?d=w1eae115bea2f4a5abc6bded608a65ddd

SISG Report: Presented by Klaus-Juergen Schulz

Mr. Schulz provided an executive summary of the SISG and its activities. Since IOP-3, CCSDS has published the basic technical standards to enable DTN and a network-centric space communication architecture. Multiple space agencies have performed various DTN ground demonstration and DTN (running on laptop computers) is now operational onboard the ISS, supporting payload data transmission. However, the introduction of DTN into future missions still requires development of DTN implementations in flight systems. The IOP-3 emphasized the use of DTN for Lunar and Mars relay missions and several upcoming LEO missions plan to implement DTN, which will demonstrate applicability and efficiencies. Mr. Schulz added that the benefits of DTN are especially apparent when it is used to maximize link utilization with high-speed Ka-band and optical links, which are both weather dependent. He also reminded the delegates of the SISG's charter, membership, and IOP-3 resolutions.

Dr. Afarin presented an update on DTN standardization. Since IOP-3, the core standards for DTN have been published by CCSDS and standards to further the DTN architecture are in process in CCSDS. Additionally, the Internet Engineering Task Force (IETF) established a DTN Working Group in 2014 in which key CCSDS members participate to ensure compatibility. This indicates interest and developments in DTN beyond civil space agencies.

Mr. Schulz noted that since IOP-3, internetworking has been infused into operations, demonstrated, and implemented. NASA began to use DTN as an operational service for ISS payloads following an extended period of multi-agency demonstrations; it was demonstrated by JAXA DRTS, NASA LLCD, and NASA Antarctica-to-ISS; there were software implementations of DTN protocols which were proven to be interoperable; and some implementations are available as open source software, facilitating developments. Mr. Schulz also listed the planned space internetworking demonstrations and implementations. A visual of a multi-agency space internetworking demonstration can be found in the associated document. Demonstrations of network-layer cross support with DTN implemented onboard LEO spacecraft and within agency ground stations are recommended within the next three years. He added that it is essential to demonstrate in flight demo capabilities to be more convincing for future projects to pick up the capability.

There has been progress in the last 5 years with the publication of standards, first mission operations and demonstrations, and shifting the emphasis towards implementation and infusion. Additionally, the role of DTN for high-rate communications for weather-sensitive links (optical and Ka-band) is better understood, including previously de-emphasized LEO mission scenarios. The standardized high data rate transmission technology in a standardized network-centric communications architecture with Bundle Protocol enables the overall next-generation space communications solutions. The introduction of DTN standard products will decrease development costs and increase mission operations productivity.

Mr. Schulz presented the SISG's proposed resolutions. Referencing Resolution #2, Mr. Pradeilles asked why the IOP needs to be so specific about DTN flight implementations. Mr. Liebrecht agreed that there is too much detail for a resolution. The Chairman concurred and noted that the resolution should just recognize the advantages in utilizing DTN to enable a higher data rate. Mr. Schulz acknowledged the delegates' comments to generalize the resolution.

Referencing Resolution #4, Mr. Soula asked Mr. Schulz to clarify what type of relay he recommends be equipped with DTN nodes, because the wording implies that the group is proposing any relay satellite be equipped with DTN. Mr. Cosby recommended modifying the text to indicate specifically cross support relays and not any relays. Mr. Schulz agreed to this change.

Mr. Pilgram asked why the SISG didn't mention network security. Mr. Schulz answered that the emphasis was on bringing about the first steps of network architecture and then adding onto that in the future. Mr. Younes noted that all experiments until now have been single hop and security is well contained. To move forward to multi hop, the security aspect is critical and needed to invest money in the 2021 timeframe from the NASA perspective.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/SISG%20Report%20IOP-4%20v3.pptx?d=w0682bdabf4394b418ca015b4924ad7e9

MOSSG Report: Presented by Ian Harrison

Mr. Harrison reviewed the membership of the MOSSG which includes CNES, CSA, DLR, ESA, JAXA, and NASA. He noted that although the agencies changed over the course of the group's work, the number of participants was generally 6. The MOSSG was created when mission operations functions were added to the IOAG Charter at IOP-3. Its objectives are to: address interoperability topics between the agencies, assess the potential benefits in the medium and long term, assess whether a simulation is needed to quantify benefits to be gained, develop a Service Catalog of Mission Operations Services (SC #3) and a study report, and report progress in the mission operations systems area at IOP-4. Mr. Harrison also reviewed the definition of interoperability as defined by CCSDS as background for the presentation and noted that CCSDS joined in on meetings when necessary.

The group met on a regular basis to fulfill the mandate and the initial work plan was revised to allow for more timely completion with available resources. Service Catalog #3 and the MOSSG Report and Roadmap were delivered to the IOAG for review and approval. It was noted that the primary goals of the group have been achieved and recommendations were made on potential follow-on activities.

Mr. Harrison presented a visual of the SC #3 structure which can be found in the associated document. He commented that it is a very large domain to focus on and so was reduced to ground-

to-ground services. The services included telemetry, command, data access, planning, navigation, and support. The group believes that interoperability interfaces should be able to serve as an interface between agencies and not intrude on them. There are many benefits in trying to standardize ground-to-ground as much as possible, particularly with large multi-agency programs. Interoperability standardization is in the early stages for ground segments to prevent agencies needing to reinvent their interfaces down the line. In January 2019 a multi-agency meeting on ISS and the Gateway operations will discuss benefits of using standard interoperability interfaces.

Additional notes that the MOSSG emphasized were that there is value in both service-based interactions and formatted message exchange approaches to interagency interoperability, any approach should not intrude on the internal designs of any agency, and interfaces between agencies should be kept as simple as possible. Mr. Harrison also noted that CCSDS has developed standards that support many of the needs listed in Catalog #3 and the MOSSG did not fully assess the adequacy of each CCSDS standard. The MOSSG has also used the term Mission Operations Interoperability Services (MOIS) to avoid confusion with the CCSDS term Mission Operations (MO) services, which has a broader scope than just ground-based interoperability. Other notes outlined by the MOSSG include: priorities for development of standards are set by the IOAG and not by the MOSSG, an interface gateway approach where agencies interact following well defined standards is recommended as an initial adoption approach and is a candidate for near-term multi-agency prototyping, and large multi-agency programs should consider interoperability from the start with appropriate applicable standards used.

Mr. Harrison outlined options for the future of the MOSSG. Currently, the MOSSG effort is scheduled to end following the IOAG acceptance of the report and Service Catalog #3 and the conclusion of IOP-4. Following IOP-4, the MOSSG could “hibernate” and be available as a mission operations resource for other IOAG activities and working groups as needed, be extended as the same group, or be re-chartered as a new working group defined to accomplish additional mission operations interoperability activities. This may include: 1) helping to coordinate the activities required to develop interagency interface gateway testbeds and promote infusion of the Catalog #3 services (recommended by the MOSSG team); 2) looking beyond the current “ground system-to-ground system” focus and include evolving operations concepts that treat the onboard systems as part of the large system of systems associated with mission operations resulting in a new Service Catalog; or 3) serve as a resource to help address mission operations needs of the very large interagency programs being considered covering Mars exploration and the Lunar Orbital Platform-Gateway.

Mr. Liebrecht referenced the idea to help coordinate activities required to develop interagency interface gateway testbeds and promote infusion of SC#3 and asked if the working groups had any ideas for a reasonable mission where this could be attempted. Mr. Harrison responded that new or existing missions could be used. The IOAG may down-select and focus on a subset of the catalog instead of the full catalog and identify infrastructure the mission could focus on. At least 3 agencies would need to participate to show interoperability. Mr. Soula noted that there was an IOAG action

to gauge interest in participation for this demonstration. The delegates noted to check responses to the action already completed on this topic.

Mr. Harrison presented the MOSSG's proposed resolutions. The Chairman commented that the wording of Resolution #2 would need to be changed because the Catalog can not be approved if it isn't accessible.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/MOSSG%20IOP4%2020181213.pptx?d=w5bd961a6c5784950a6e7f9b4025bca21

LCAWG Report: Presented by Matthew Cosby

Mr. Cosby provided an overview of the LCAWG work items, including to identify key issues concerning interoperability and cross support among the missions/network assets operated by the IOAG member agencies; generate a recommendation for the down-selected frequency, modulation, ranging, and coding for the future lunar architecture for input to the LOP-G; and define relay services, service types, the Lunar-Earth Space Internet, and the Lunar Relay Network (including the need for dedicated relay orbiters and determining their optimal orbits and performing coverage analysis and link analysis, as well as assessing the capabilities of the currently planned relay orbiters). The purpose of the study is to define the future Lunar Communications Architecture that will facilitate potential cross support to Lunar missions by communication assets owned and/or operated by the IOAG member agencies and their affiliated companies in the private sectors. Mr. Cosby also provided an overview of active membership and representation in the working group. Work across working groups was also enabled.

The working group identified the potential Lunar mission to be launched during the 2018-2028 timeframe by the IOAG member agencies. This includes 28 missions, 26 vehicles, 21 confirmed cross-supported missions, and 6 missions still determining cross support. He noted that private sectors endeavors are not listed in the summary due to uncertain launch dates, commercial sensitivity, and a lack of involvement, however, the group is assuming they do require cross support due to evidence of them talking to agencies about providing services.

The down-selection of frequency, modulation, ranging, coding, and space data link protocols is driven by the need for lower cost which can be achieved by interoperability among future Lunar missions, including LOP-G and Lunar surface science missions. It's been recognized that the set of CCSDS standards are key to the design of the Lunar space communications architecture and given the rich repertoire of the standards produced by the CCSDS, it is imperative for the IOAG to pick and choose the suitable subset of standards as the solutions to the problems. The working group has interacted with the ISS Exploration Capabilities Study Team (IECST) and ISECG and incorporated input into the requirement document "International Communication System Interoperability Standards (ICSIS)." Approximately 40 CCSDS standards have been accepted by the Gateway that the proposed architecture will support. The factors taken into account for the

selection of CCSDS standards include: interoperability between the lunar vehicles (orbiters, landers, rovers) and their supporting network assets (owned by IOAG member agencies and commercial providers), interoperability between a lunar relay orbiter and its user vehicles, costs of implementation, and constraints due to spectral limitation (ITU, SFCG, and NTIA imposed). Mr. Cosby emphasized that the group ensured that they only identified things that still need to be considered and are not reinventing anything.

The LCAWG defined relay data service as an end-to-end service that offers the transfer of a single interoperable entity over one or more assets (i.e. relay assets) between the two end points. This single interoperable entity must be at, or at a higher level than Layer 3 on the ISO model. This single interoperable entity shall be created at the start point and preserved during its transition through the relay asset(s) until acceptance at the end point. For the lunar communications architecture, this data entity is a bundle packet. In addition to the relay data services, the involved relay asset(s) may provide other types of service (e.g. network time service, in-situ tracking service, and in-situ navigation service). The relay services are end-to-end service involving multiple physical links (proximity link, Direct-to-Earth links, Direct-from-Earth link) and interfaces at multiple layers (physical, data link, and network layers). The exhibition of network layer service and multiple links across two planetary bodies, Moon and Earth points to the need for defining an Interplanetary Space Internet.

Mr. Cosby displayed a visual of the proposed lunar relay architecture which may be found in the associated document. He noted that multiple access and user initiated relay services are missing and there should also be more automation. In addition, the high data rate uplink coding and protocol and the elements of that protocol needs to be finalized. Mr. Tai added that real-time determination for a service vehicle using a relay link is yet to be defined by CCSDS.

The LCAWG has reached consensus for the frequency, modulation, coding, ranging, space data link, and network layers for the Lunar communications architecture. In the 2020s, for the Lunar relay network, the USLP offers the ability to interoperate by multiple relay orbiters at the data link layer. Space Internetworking-over-DTN further allows them to interoperate at the network layer. At least 2 relay orbiters are on the same path towards provision of relay data services. Also in the 2020s, adopting S-band for proximity links by multiple relay orbiters enables the in-situ tracking service and possibly the in-situ navigation (GNSS-like capability). At least 3 relay orbiters could collectively serve as a navigation satellite constellation to support the South Pole surface vehicles. Ultimately, for the future international Lunar exploration at a global scale, the IOAG may want to coordinate with its member agencies and private industry to incrementally build up a lunar network. For example, 3 relay orbiters to serve user vehicles (on surface and in orbit) in both poles, far side, near side, and equatorial regions.

The Chairman asked how the IOAG intends to close the gaps in standardization. Mr. Cosby responded that the Report identifies this, but it is not up to the working group to come up with all

the solutions. Mr. Tai added that the working group reviews and identifies missing standards to give input to CCSDS on standardization.

Mr. Baldwin noted that he is surprised that there was no definition of relay services by CCSDS, because CCSDS has standardized services around the Earth. Mr. Tai responded that CCSDS has just not defined multiple access for proximity links. Mr. Cosby added that the group is trying to move away from the need for a TDRS-like service in order to run DTN.

Mr. Cosby concluded by presenting the LCAWG's proposed resolutions. Referencing Resolutions #1 and #2, Mr. Liebrecht suggested that the IOP provide its endorsement of the Lunar communication architecture and the use of down-selected communication standards after they have been finalized. The Chairman acknowledged Mr. Liebrecht's comments.

The associated document for this presentation may be found at:
https://www.interoperabilityplenary.org/Interoperability%20Documents/Lunar%20Communications%20Architecture%20Working%20Group%20(LCAWG)%20IOP%20Presentation%20v3.0.pptx?d=wfff92ad5333b4f03ac4c354769ff68fa

IOP-4 Meeting Minutes
Oberpfaffenhofen, Germany
20 December 2018

Review of IOP-4 Leadership Forum: Moderated by the Chairman

Future Role of Agencies

The potential role of the IOAG may be to act as a bridge between institutional organizations and the commercial side. The difference between these entities was emphasized. Institutional organizations will remain as such and are looking for specific cooperation on missions, particularly on the scientific side. The commercial side has a much different purpose and there should be exchange between the two. UKSA proposed involving industry in a forum at the next IOAG meeting, but the idea requires further discussion in the IOAG and whether the final proposal should be approved by the IOP. Mr. Schulz asked if the IOP should clarify certain rules for interaction with industry. For example, ensuring that there isn't preference given to certain companies. The Chairman noted that one option is to make a proposal to discuss internally and the other option is to discuss within the IOP and receive guidance. The IOP currently isn't able to give a clear indication of which direction to go for setting up the interaction because it would require other discussions. Mr. Liebrecht noted that the discussion could happen virtually if needed.

Future Trends

Currently, hundreds of people are needed to operate satellites and new technologies are emerging that should find their way into operations. These technologies are being discussed at different agencies and the IOAG could be a place to give recommendations and assess the technologies. The scope of the IOAG Charter could be widened to look at these types of technology. Mr. Liebrecht noted that the IOAG has historically looked ahead at emerging technology that member agencies determined could be helpful. The IOAG sets up a group to think about these technologies and develop a report for adoption, followed by interacting with CCSDS for implementation. The Chairman commented that the IOAG is now talking about automation and artificial intelligence on the operations side, so this will require further discussion on whether the IOAG should address these topics.

Space Traffic Management

The Chairman noted that the terminology for space traffic management isn't clear and what its relevance for the IOAG is. The IOAG could potentially act as a body for exchanging information, but this topic will have to be discussed in further detail at future meetings.

Review of IOP-4 Liaison & Working Group Presentations

The Chairman noted that there weren't any controversial discussion in response to the liaison presentations and the interaction with different groups is working well.

C&MWG
Dr. Afarin noted that he accepted the recommendations discussed by the IOP.

SECSWG
Ms. Barclay noted that there was significant discussion on multilateral and bilateral agreements. The conclusion is that the group is defining procedures to shorten lead time that may be called up by various agencies if a service is required in a spacecraft emergency.

LEO26WG
The Chairman acknowledged the recommendations made by the IOP on the relevance of the group, especially relating to the commercial market. He suggested further discussion on the scope of the group and expanding it to deep space.

OLSG
The Chairman noted that there were many benefits to optical communications identified and there was a good exchange of information with no controversial issues. The important takeaway is that the IOAG has in the past looked more into the technology side and it now needs to be infused. It's not clear how this technology will be infused in the ground infrastructure.

SISG
The Chairman noted that there was nothing controversial on this topic. There was agreement on the recommendation from NASA to use DTN for all platforms, because it seems to be the future protocol for space internetworking.

MOSSG
The Chairman acknowledged that there is an advantage to interaction between control centers. The problem is that Service Catalog #3 hasn't been formally reviewed and approved, so a formal recommendation can't be made for implementation.

LCAWG
The Chairman noted that the LCAWG has a similar problem to the MOSSG, because its formal report hasn't been reviewed and endorsed.

Review of IOP-4: Communique

The delegates reviewed the IOP-4 Communique and provided minor edits in real time. The Chairman noted that he would distribute the Communique for final approval and review.

Open Discussion

Mr. Tachi suggested reviewing recommendations to determine if they're practical within the timeframe between IOP meetings. The Chairman suggested having an IOP interaction between

formal IOP meetings and Mr. Soula added that since there is no set timespan between IOPs, the Leadership Forum could capture what is changing in the space landscape and what needs to be addressed. JAXA took an action to determine a less formal forum for exchange between agencies at a higher level. Mr. Pradeilles suggested holding the Leadership Forum in conjunction with other conferences, such as SpaceOps. Mr. Liebrecht noted that the Leadership Forum could be held virtually, but Mr. Forsythe responded that he would prefer an in person meeting. The Chairman added that the scope could cover a wider perspective than current IOAG activities and the IOP can endorse or deny the proposal for this.

There were no further comments, so the Chairman thanked the attendees for their participation and showing interest in the work of the IOAG. He noted that the IOP-4 had the largest participation of any other IOP meeting, involving 12 space agencies. The Chairman then closed the meeting.

Appendix A: Actions

AI 4-02: All agencies to discuss extension of IOAG charter to assess new services and technologies. [Assigned to: All Agencies. Due date: 29 March 2019]

AI 4-03: All agencies to consult experts regarding ongoing space traffic management efforts to avoid duplication of efforts. [Assigned to: All Agencies. Due date: 29 March 2019]

AI 4-04: JAXA to make proposal on holding Leadership Forum in conjunction with major space conferences for more regular occurrence of meetings. [Assigned to: JAXA. Due date: 8 February 2019]

Appendix B: Acronyms

ACM	Adaptive Coding and Modulation
AI	Agenda Item
AI	Action Item
ASI	Italian Space Agency
CCSDS	Consultative Committee for Space Data Systems
CEPT	Conference of Postal and Telecommunications Administrations
CMWG/C&MWG	Coding & Modulation Working Group
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration

CPM	Conference Preparatory Meeting
CSA	Canadian Space Agency
DLR	German Space Agency
DTE	Direct To Earth
DTN	Disruption Tolerant Networking
ESA	European Space Agency
GEO	Geosynchronous Orbit
GER	Global Exploration Roadmap
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDR	High Data Rate
HEO	High Earth Orbit
HPE	High Photon Efficiency
ICG	International Committee on GNSS
ICSIS	International Communication System Interoperability Standards
IECST	ISS Exploration Capabilities Study Team
IETF	Internet Engineering Task Force
IMT	International Mobile Communications
IOAG	Interagency Operations Advisory Group
IOP	Interoperability Plenary
IP	Internet Protocol
ISECG	International Space Exploration Coordination Group
ISL	Inter Satellite Link
ISO	International Organization for Standardization
ISS	International Space Station

ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
KARI	Korean Aerospace Research Institute
KSAT	Kongsberg Satellite Services
LCAWG	Lunar Communication Architecture Working Group
LEO	Low Earth Orbit
LEO26WG	Low Earth Orbit 26 GHz Working Group
LMWG	Lunar Mars Working Group
LOP-G	Lunar Orbital Platform-Gateway
MO	Mission Operations
MOIS	Mission Operations Interoperability Services
MOSCG	Mission Operations Systems Coordination Group
MOSSG	Mission Operations Systems Strategy Group
NASA	National Aeronautics and Space Administration
NTIA	National Telecommunications and Information Administration
OLSG	Optical Link Study Group
PNT	Positioning, Navigation, and Timing
PPE	Power and Propulsion Element
RF	Radio Frequency
SC	Service Catalog
SANSA	South African National Space Agency
SCWG	Service Catalogs Working Group
SECS	Spacecraft Emergency Cross Support
SECSWG	Spacecraft Emergency Cross Support Working Group
SFCG	Space Frequency Coordination Group

SISG	Space Internetworking Strategy Group
SOP	Standard Operating Procedure
SSC	Swedish Space Corporation
SSV	Space Service Volume
STM	Space Traffic Management
TDRS	Tracking and Data Relay Satellite
TT&C	Telemetry, Tracking, & Command
UAESA	United Arab Emirates Space Agency
UKSA	United Kingdom Space Agency
UN	United Nations
USLP	Unified Space Link Protocol
VCM	Variable Coding and Modulation
WG	Working Group
WRC	World Radiocommunication Conference