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The IOAG Working Group on Sustainability of Operations in Space (SOS WG): Findings and Recommendations in Spectrum Operations

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Abstract

In 1999 the space operations leadership of seven space agencies chartered the Interagency Operations Advisory Group (IOAG). The IOAG is pro-actively defining the future of space operations architectures and 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.

In 2019 the IOAG established the Space Operations Sustainability Working Group (SOS WG) because its member space agencies were sharing concerns on the evolution of the operations in space due e. g. to the rapid increase of operational satellites and the growing population of catalogued space debris triggering a need to assess the new risks on the operations conducted in space and to evaluate if the existing processes and coordination are sufficient. In 2021 the SOS WG published a first report covering findings and recommendations in the domains of space debris and collision avoidance and end of life activities. This report was extended to cover the domain of spectrum and interferences which was released in 2022.

Following an introduction of the IOAG and the SOS WG this paper summarizes the work done by the SOS WG in all domains and expand the key findings in the domain of spectrum and interferences and related recommendations to space agencies, the Space Frequency Coordination Group (SFCG), ground station operators and service providers, national and international regulators, satellite designers and operators.

Awareness across the broad satellite community, and not only within government space organizations or regulatory bodies such as the ITU, is essential for the sustainability of operations in space and this idea drove the formulation of the report's recommendations. Whereas the SOS WG considers it beneficial to achieve adherence to the outlined recommendations by as many operators as possible it is essential that future policies, plans, and procedures consider the variety of satellite organization types and ability to comply

Keywords: Operations, Sustainability, ITU, SFCG, Spectrum, Cross-support.

Acronyms/Abbreviations

API	Advance Publication Information
CCSDS	Consultative Committee for Space Data Systems
CDM	Conjunction Data Message
COLA	Collision Avoidance
DISCOS	Database and Information System Characterising Objects in Space
EESS	Earth Exploration Satellite Service
GNSS	Global Navigation Satellite System

IADC	Inter-Agency Space Debris Coordination Committee
IOAG	Interagency Operations Advisory Group
IOP	Interoperability Plenary
ISO	International Standards Organization
ISS	International Space Station
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
LEO	Low Earth Orbit
NEO	Near Earth Object
RB	Radiocommunication Bureau
RFI	Radio Frequency Interference
RR	Radio Regulations
RRB	Radio Regulations Board
SDM	Short-Duration Mission
SFCG	Space Frequency Coordination Group
SO	Space Operation (service)
SOS WG	Space Operations Sustainability Working Group
SRS	Space Research Service

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1. Introduction

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 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 the IOAG 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 [1].

In a meeting of the governing body of the IOAG, the Interoperability Plenary (IOP-4), held in Oberpfaffenhofen, Germany on 18~20 December 2018, the IOP delegates recommended that the IOAG:

a. evaluates the relevant issues and potential threats related to sustainable space operations and its implications for space traffic management initially in the vicinity of the Earth.
b. deals with the technical and operational perspective.
c. produces a situational report including recommendations on mitigation measures.

In response to this the IOAG established the Space Operations Sustainability Working Group (SOS WG) because its member space agencies were sharing the same concerns on the evolution of the operations in space:

- There is a rapid increase in the population of operational satellites, in particular on the non-institutional side, with new types of operations (particularly cubesat & nanosat constellations, for LEO based communication services, there are also good number of satellites added for earth observation by many private operators across the globe) and
- There is a growing population of debris in space and the space objects catalogues will contain smaller and smaller debris, and
- There is a need to assess the new risks on the operations conducted in space (including collisions, spectrum, space weather, proximity operations, etc.) and to evaluate if the existing processes and coordination are sufficient to deal with these new paradigms.

The objective of the SOS WG is to analyze the changing dynamic situation of how operations are conducted in space and the evolving trends related to the new users and the new usages of space, to:

- Verify understanding of the new or increasing risks to be considered in various domains of the operations in space (disposal operations, collision avoidance, maneuver coordination, space weather, re-entries, spectrum, interferences, in orbit servicing, proximity operations, etc...);
- Identify the international organizations that already address most of these/part of these challenges;
- Analyze the aspects covered by the space organization on their adequacy or the need of improvements if necessary;
- Formulate recommendations/requests for endorsement by the IOAG, that could be addressed to
    - Identified Organizations, or
    - Standardize the organization's operations/procedures, as required, or
    - the IOAG itself who could adopt and promote messages in space operations fora;
- Propose what role the IOAG could play in the future with respect to the SOS issues.

In 2021 the SOS WG published a first report [2] covering findings and recommendations in the domains of space debris and collision avoidance and end of life activities. This report was extended to cover the domain of spectrum and interferences which was released in 2022 [3] with small updates in the other domains included.

While, IOAG is proposing the recommendations, it should be noted that the IOAG is not a regulatory body and that this paper, including its findings and recommendations, remains non-binding and subject to decisions by individual agencies and nations.

Following this introduction, the paper will summarize the work done by the SOS WG in all domains and expand the key findings in the domain of spectrum and interferences and related recommendations to space agencies, the Space Frequency Coordination Group (SFCG), ground station operators and service providers, national and international regulators, satellite designers and operators.

The recommendations contained in this paper will be more viable and feasible as more and more organizations choose to implement them, come out with issues (if any) to modify the recommendations resulting in robust solutions. Although this report has been developed by multiple civilian space agencies, many of the concepts apply to space assets of a variety of organizations, including:

- Civilian space agencies
- Government military space organizations
- Commercial satellite organizations
- Independent research organizations
- Academia – including University and even High School satellite developers
- Launch operators
- Entities providing or coordinating relevant infrastructure and resources, such as
    - ITU
    - Surveillance system operators and service providers

Adherence to the outlined recommendations by as many operators as possible hopefully helps to achieve that future policies, plans and procedures consider the variety of satellite organization types and ability to comply.

To meet the objectives assigned by the IOAG, the SOS WG was elected to initiate a study on each of the following domains of concern:

- Space Debris and Collision Avoidance
- End of life activities
- Spectrum and interferences

Other domains which were identified as potential areas of concern for sustainable space operations are considered future topics for the WG, currently:

- Space Weather;
- Proximity operations, in-orbit services.

For each domain, new and growing risks to the sustainability of space operations were identified by the WG (referred to as "Findings" in the report). The report identifies certain risks involved, measures to be taken, relevant

national and international entities responsible for the measures and suggests specific recommendations to be implemented. Before issuing the final report, these recommendations were discussed threadbare with domain-specific experts and accordingly modified and improved upon.

The following figure highlights the process followed by the SOS WG in defining and performing the analysis as described above.

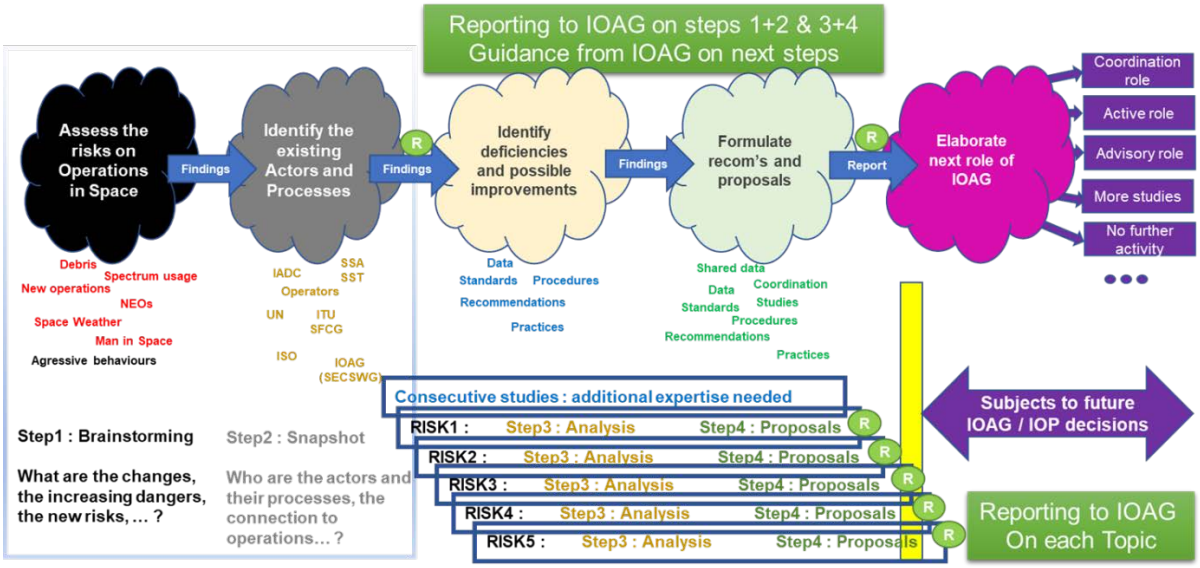

Fig. 1 SOS WG risk analysis process

2. Domain of Space Debris and Collision Avoidance

In this domain, the WG has expressed concerns with respect to the proliferation of space debris and the need to perform more frequent collision avoidance maneuvers. The WG's work is summarized in 9 findings and related recommendations addressing operators of satellites, maintainers of catalogues, space agencies, satellite designers, launch service providers, IADC, academia and researchers, national and international regulators.

The full report is available as [3].

3. Domain of End of life activities

Those Missions having no preparations/plans for their end of the life activities/operations will increase the risks of additional debris creation through collision and fragmentation. The WG's work in this domain is summarized in 6 findings and related recommendations addressing operators of satellites, space agencies, IADC, national and international regulators, and ISO.

The full report is available as [3].

4. Domain of Spectrum and Interferences

Increasing difficulties in sharing the spectrum and in avoiding Radio Frequency Interferences (RFI) have been identified, in the frequency bands used for Space Operation (SOS), Space Research (SRS) and Earth Exploration Satellite (EESS) services. This section summarizes participants' findings and recommendations with regard to these concerns.

4.1 Finding 1. Reporting on environment of radio frequency interference to SOS/SRS/EESS communication services

The growing number of space stations increases the potential for radio frequency interferences and the need for frequency coordination. However, the current coordination is sometimes based on rather simple models and geometric constraints while at the same time there is a lack of actual data on past occurrences of interferences which would potentially allow to establish more stringent constraints under which interferences may occur for SOS/SRS/EESS communication services.

The Resolution SFCG A36-2R1 asks SFCG members to report on RFI cases for passive sensors. Similarly, it is useful that the space agencies report and collect information on actual interference events (frequency band, geometry, antenna characteristics and frequency of occurrence) for conducting research, calibrating the refined models with the reported data and extrapolating to a future with the increased traffic. Further, a report of these findings should be published for usage by other entities including commercial tracking service operators.

Recommendation to SFCG

The IOAG/SOS WG recommends SFCG to consider establishing a resolution similar to the Resolution SFCG A36-2R1 for encouraging SFCG members to report to the SFCG meeting instances of harmful interference to the SOS/SRS/EESS communication services and to recommend realistic models which should be used to assess the conditions under which interferences happen.

4.2 Finding 2. Filing of satellites at the ITU-R

Commercial operators of non-geostationary satellite systems, in particular in the case of constellations, do not systematically follow the basic principle of using the frequency resource as efficiently as possible. Their initial filing (API) often doesn't contain detailed and accurate information on frequency bands, orbit parameters, location of ground stations, etc. In many cases, the whole of the frequency allocation is reserved.

As a result, other administrations have no means to perform meaningful study on the potential impact on existing or future satellites that their operators may have. Administrations may issue comments, but after a time, the filing will be considered approved and, as a result, will have precedence over other satellite systems that will be filed at later dates. The planned target orbit, the exact frequencies or the ground segment are provided at the time of notification. That is, only at the time of notification, issues with pre-existing systems may be discovered, which would make the coordination difficult at a late stage of the new system implementation.

Providing details long in advance to the launch can be challenging. However, seeking precedence at the time of the API filing should not be at the expense of providing the necessary detailed information.

The ITU-R WP7B is currently addressing the issue and is developing recommendations for S-band (SOS/SRS/EESS) so that the National Frequency Administrations may improve the practices and therefore the filing declaration manner (Refer to Appendix A for recommendations being developed). In particular, submitting a filing with generic parameters should be discouraged and provision of details on actual frequency bandwidth, station locations and other technical parameters should be requested for initial compatibility assessment.

Recommendation to space agencies

The IOAG/SOS WG recommends that the space agencies approach their National Frequency Administrations to facilitate the initiative of the ITU-R WP7B in improving the filing process and the details to be provided for new satellite systems in all frequency bands. The IOAG/SOS WG recommends to include constellations in such ITU-R recommendation.

Recommendation to satellite operators

The IOAG/SOS WG recommends that the satellite operators provide the necessary set of parameters (orbit, actual center frequency, actual frequency bandwidth, ground station locations…) in the filing of their satellite(s) from the API stage, to allow the proper evaluation of the risks of interference, at early stage, with other satellite systems.

Recommendation to national and international regulators

The IOAG/SOS WG recommends that the national and international regulators add to the criteria to get the authorizations for launch, a necessary set of conditions relative to the declaration of satellite systems at the ITU-R, in particular to make sure sufficient information is available, long in advance to the launch(es), to enable a proper coordination with other satellite systems.

4.3 Finding 3. Protection of the S-Band

The SOS/SRS/EESS S-Band needs to be protected as it is a unique asset used by all the members of IOAG and a large part of the space community. Recognizing that the utilization of the frequency band is increasing for uplink and downlink of multiple missions, the risk of interference is growing and mitigation techniques are required.

For instance, mitigation techniques to be considered include:
- reducing further the allowed bandwidth to avoid the band is used extensively for mission data,
- making the usage of limited bandwidth for housekeeping data become the rule again,
- establishing a reasonable ground station antenna size and recommending the minimum EIRP,
- using multiple frequencies per satellite to allow hopping,
- using CDMA spread spectrum,
- using higher level protocols to secure retransmission of the lost frames (e.g. CCSDS COP-1; DTN).

On the ground, the cases of high or low latitude stations, small or large dishes, multi band antennas, collocated antennas should be considered. Onboard the satellites, among other aspects, the antenna patterns should also be considered.

The ITU-R WP7B and SFCG have already a set of recommendations and resolutions in place, to define limitations and to mitigate the risks of interferences in the S-Band (Refer to Appendix A for relevant Recommendations/Resolutions).

Further, the SFCG is currently discussing the issue of using small dishes and will study further the conditions to use small antenna dishes for uplink and may define if a hard limit on minimum antenna diameter should be recommended.

These issues need be addressed globally, at system and network levels, considering the contributions of ground and space systems to the risks of interferences on the uplink and downlink. They must be formulated so that they are applicable to commercial operators as well.

The ITU-R WP7B is in the process of developing recommendations on better sharing of the spectrum (e.g. bandwidth limitation, CDMA Spread Spectrum…). While the issue of small dishes is not elaborated in the draft recommendations, strict conditions are developed.

Recommendation to SFCG

The IOAG/SOS WG recommends that the SFCG continues to recommend techniques for the efficient usage of the SOS/SRS/EESS S-Band so as to mitigate the risks of interferences in that Band, both for uplink and downlink, and which corresponding recommendations should be put urgently in place to address the growing demand from new operators. This should be addressed at the system level and must consider the latitude of the stations and the type of antennas, in particular if combined with X-Band or Ka-Band (26 GHz).

Recommendation to space agencies

The IOAG/SOS WG recommends that space agencies approach their National Frequency Administrations to facilitate the initiative of the ITU-R WP7B to develop S-Band recommendations and adopt the techniques that best guarantee long term sustainability for both uplink and downlink.

Recommendation to satellites designers

The IOAG/SOS WG recommends that the satellite designers adopt the recommended techniques that allow to mitigate the risks of interferences in the SOS/SRS/EESS S-Band, and in particular to limit the usage of wide antenna beams on the satellite Tx antenna (e.g. isoflux antennas) to special phases of the mission such as LEOP or Emergency, to the extent it is practical.

Recommendation to satellite operators

The IOAG/SOS WG recommends that the satellites operators adopt the techniques recommended by the ITU WP7B that allow to mitigate the risks of interferences in the SOS/EESS/SRS S-Band at system level, and to limit the usage of the band for housekeeping data and use those techniques that make the links less sensitive to short interferences.

Recommendation to the national and international regulators

The IOAG/SOS WG recommends that the national and international regulators add to the criteria to get the authorizations for launch, a necessary set of conditions relative to the efficient usage of the SOS/SRS/EESS S-Band and the application of RFI mitigation techniques. Such criteria could be elaborated with the National Frequency Administrations and be made consistent with ITU-R recommendations.

4.4 Finding 4. Protection of the 8 GHz Band

The use of this frequency band by EESS operated by various space agencies and commercial entities for data downlink operations, as well as by other terrestrial services, has been increasing and could result in harmful interference among these operators. Potential difficulties in sharing the heavily used 8 GHz spectrum may be avoided if EESS satellite designers and operators could apply suitable mitigation methods provided in ITU-R and SFCG Recommendations (Refer to Appendix A for relevant Recommendations).

Recommendation to satellite designers and operators

The IOAG/SOS WG recommends that the satellites designers and operators comply with the recommendations of the ITU-R and SFCG for the protection of the 8.025 to 8.4 GHz frequency band.

4.5 Finding 5. Protection of the 26 GHz Band

Future EESS/SRS and space research missions will rely on the 26 GHz band to downlink their data. A regulatory framework is needed worldwide to safeguard these missions. The possible coexistence of International Mobile Telecommunications (IMT), which will operate in the newly allocated 26 GHz-band, may generate aggregate interferences in EESS/SRS Earth stations. The ITU has published the ITU-R Recommendation SA.2142 to provide necessary coordination area for the EESS/SRS receiving Earth stations in the 26 GHz band. (Refer to Appendix A for relevant ITU-R/SFCG Recommendations). Adopting such a recommendation on national and international level would be helpful.

Recommendation to space agencies

The IOAG/SOS WG recommends that the space agencies approach their National Frequency Administrations to facilitate the adoption of the ITU-R Recommendation SA.2142 for ensuring the protected use of existing and planned EESS/SRS receiving Earth stations and for future deployment of Earth stations in the 26 GHz band.

Recommendation to the national and international regulators

National Frequency Administrations should support regulatory measures in their respective jurisdiction, to ensure the protected use of existing and planned EESS/SRS receiving Earth stations and for future deployment of Earth stations in the 26 GHz band.

4.6 Finding 6. Increasing difficulties of frequency coordination and avoidance of interferences

The increase in the number of (planned) active satellites (e.g. SmallSats and constellations) that use EESS/SRS/SOS radio frequency increases the risk of interference and thus necessitates an increased need for coordination. Beyond this increase, avoiding interferences is complicated by:

- New operators often lack the knowledge and manpower on the ITU-R process and the RR, and the knowledge of mandatory procedures like frequency management is often insufficient.
- NGSO satellite systems with short duration missions (SDM) and not subject to coordination may make the resolution of potential conflict difficult. The notifying administrations may have problems to provide accurate orbital characteristics at the beginning of the development cycle and, in some instances, not even prior to the launch of the satellites. (Resolution 32 (WRC-19)).
    - *Note: Resolution 32 (WRC-19) does not relieve SDM from the requirements of the RR Articles 9 and 11.*
    - *Note: Resolution 32 (WRC-19) prevents SDM from extending the mission beyond the original 3 years or replacing such SDM, or applying the suspension provision in the RR. While the WG is not aware of an actual case where an SDM has been extended beyond 3 years, future violations could lead to longer lasting missions without proper coordination in place.*
- A space station is required to ensure immediate cessation of its radio emissions by telecommand, per RR 22.1, however, it is not clear how the BR could enforce this requirement.
    - *Note: This is a concern mainly for interferences in the GEO regime as in LEO interferences typically occur for very short durations and at non-systematic times only.*

Recommendation to space agencies

The IOAG/SOS WG recommends that space agencies approach their National Frequency Administrations to provide operators, which often lack the knowledge and manpower on the ITU-R process and the RR, with guidance/advice for them gaining sufficient knowledge of the ITU-R mandatory procedures for frequency management and coordination.

The IOAG/SOS WG further recommends that space agencies approach their National Frequency Administrations to work towards ITU-R to establish:

- a requirement on to-be-operators of SDM and constellations to share immediately technical and operational information of their network/system with the ITU-R in order to be easily accessible by concerned administrations/operators and a mechanism in place in the Radiocommunication Bureau (RB) so that the ITU-R via its RB could intervene quickly to resolve a case of a complaint effectively,
- a requirement for SDM that the period of comments to SDMs filings should be reduced in order to have a quicker processing period,
- a mechanism for an implementation of RR 22.1 which require space stations to ensure immediate cessation of its radio emissions by telecommand, in case of harmful inference occurring or predicted during a long- or repetitive-time span.

Recommendation to national and international regulators

The IOAG/SOS WG recommends that national and international regulators be more active in educating new operators and other newcomers on their ITU-R obligations and mandatory procedures for frequency management and coordination.

Recommendation to national and international regulators

The IOAG/SOS WG recommends that national and international regulators establish, apply and enforce rules preventing missions previously registered as SDMs from extending their mission beyond 3 years.

4.7 Finding 7. Coordination on the downlink times

The increase in number of EESS spacecraft, combined with an increase in mission payload data volume (per spacecraft) lead to an increase of the risk of interference which may not be possible to avoid on mission ground segment design level (e.g. by selecting ground stations never visible simultaneously from spacecraft having potential of causing interference).

As a means of avoiding interference in actual or potential operations, the SFCG Recommendation SFCG REC 12-4R3 recommends that space agencies be prepared to temporarily switch off emissions from the spacecraft concerned, in accordance with the priority guidelines laid down in Chapter 4 of the SFCG Procedures for Inter-Agency Frequency Coordination (RES SFCG A12-1R3). (Refer to Appendix A for SFCG Recommendation/Resolution)

Further to the above means, advance coordination of timing of the planned downlink may allow to use nearby/collocated ground stations (e.g. via taking planned downlinking times of one spacecraft into account in mission planning of transmission by another spacecraft). There could possibly be a concept of mutually defining priority handling. Mechanism of exchanging downlinking times and frequencies (channels) used, and possibly the agreed priorities, may lead to CCSDS data message.

Recommendation to space agencies

The IOAG/SOS WG recommends that space agencies elaborate a concept of operations on the required coordination between satellite operators (or ground station operators) on the downlinking times of their EESS spacecraft on nearby/collocated ground stations, for frequency bands of interest, and in particular to study the required exchanges of information in the process, e.g. the CCSDS Service Management data message. In order to make this operation concept more pragmatic, it is further recommended that the space agencies study how this operations concept can be extended to the commercial entities.

4.8 Finding 8. Sharing of information on which regulations apply to each ground station

In general, regulations being more and more complex, not only at the ITU-R level, but also at the national frequency coordination or national regulation level. Being different from country to country and changing partially from year to year, it makes it hard to plan a long-term mission and, in particular, the usage over specific ground station. Wrong assumptions based on some historical information may lead to delays in projects integration.

Recommendation to Ground Station operators and service providers:

The IOAG/SOS WG recommends that the ground station operators and service providers include, in their User's Guide, up to date information on the applicable regulations for each ground station, concerning the possibilities to use the ground station, in each of the frequency bands. This way any regulatory restrictions or necessary preparation process can be considered in early phases of space projects, for instance when issuing the declaration to the ITU-R and in designing future operations.

5. Conclusions

The sustainability of space activities has become increasingly important over the last few years due to the significant rise in number of objects present in the Earth's orbit, especially in orbits close to the Earth. The large number of objects, both active and passive, the latter to be considered "space debris", constitute a serious danger to the space operations of the satellites in service.

In this paper, the IOAG working group called "Space Sustainability Operations (SOS WG)" reported the main results of the analysis work carried out in the domain of the risk of Radio Frequency Interferences (RFI) in satellite telecommunications.

The working group analyzed the possible sources of risk from interferences and therefore, issued its recommendations to the entities operating in the field of satellite telecommunications (Space Frequency Coordination Group, satellite operators, space agencies, national and international regulatory authorities, etc.) with the aim of minimize the risks and optimizing the management of the risks of interferences in space operations.

The analysis focused in particular on Radio Frequency Interferences (RFI) for identified frequency bands (S band, 8 GHz band, 26 GHz band) used for the services of Space Operation (SOS), Space Research (SRS) and Earth Exploration Satellite (EESS).

Furthermore, the analysis carried out considered the risks emerging from the new large constellations of mini and small satellites being designed and built in huge number of thousands of satellites in low orbit with a limited operating lifetime.

Lastly, the risks derived from inadequate coordination, management of ground stations and space-to-ground transmission time have also been analyzed.

While the IOAG is an inter-agency forum, the WG considers it to be important that organizations beyond its member agencies, private operators also chose to implement and adhere to the recommendations presented here. The WG also considers it is essential that, the future policies, plans, and procedures of various custodians of the satellites builder, operators, service providers consider the recommendations and diligently comply to the procedures laid out. The WG is convinced that long term sustainability of operations in space can only be achieved via strong international collaboration and agreements leading potentially to common democratic regulations via common Space Traffic Management.

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Appendix A: Status of SFCG and ITU recommendations relevant to Spectrum and Interference concerns in the present report

The table below lists the ITU-R Recommendations and the SFCG Recommendations/Resolutions which are relevant for the contents of the Findings in Section 4, the domain of Spectrum and Interferences. The SFCG member agencies have been developing a variety of recommendations and resolutions through their efforts in facilitating efficient spectrum usage and avoiding radio frequency interferences.

Legend:
ITU-R = Recommendation
SA series = Space applications and meteorology
SFCG REC = Recommendation
SFCG RES = Resolution

Finding 1. Reporting on environment of radio frequency interference to SO/SRS/EESS communication services		
Relevant resolution	*SFCG*	SFCG SFCG A36-2R1 REPORTING OF RADIO FREQUENCY INTERFERENCE TO EARTH EXPLORATION-SATELLITE SERVICE (PASSIVE) SENSORS
Document status		Published
Finding 2. Filing of satellites at the ITU		
Relevant recommendation	*ITU-R*	ITU-R Rec. SA.[S-BAND DL USE OPT] and ITU-R SA.[S-BAND UL USE OPT], Guidelines on the use of the 2 025-2 110 MHz and 2 200-2 290 MHz frequency bands by SRS/EESS/SOS satellites
Document status		Working documents towards the Preliminary Draft New Recommendation is being discussed in WP7B.
Finding 3. Protection of the S-Band		
Relevant recommendation	*ITU-R*	ITU-R Rec. SA.[S-BAND DL USE OPT] and ITU-R SA.[S-BAND UL USE OPT], see under finding 1; also applies to finding 2
Document status		
Relevant recommendation	*ITU-R*	ITU-R Rec. SA.1154 Provisions to protect the space research (SR), space operations (SO) and Earth exploration-satellite services (EESS) and to facilitate sharing with the mobile service in the 2 025-2 110 MHz and 2 200-2 290 MHz bands
Document status		Published
Relevant recommendation	*ITU-R*	ITU-R Rec. SA.2078 Protection of SRS earth stations from mobile (aircraft) stations in the 2 200-2 290 MHz band
Document status		Published
Relevant recommendation	*SFCG*	SFCG REC 12-4R3 Methods for Reduction of Potential Interference Between Systems in the Space Science Services in Densely Occupied Bands
Document status		Published
Relevant recommendation	*SFCG*	SFCG REC 21-2R4 Efficient Spectrum Utilisation for Space Research Service (Category A) and Earth Exploration-Satellite Service on Space-to-Earth Links
Document status		Published

Relevant recommendation	*SFCG*	SFCG REC 12-5R2 Limitations on Earth - Space Link Power Levels in the 2025 – 2110 MHz band
Document status		Published
Relevant resolution	*SFCG*	SFCG RES 24-1R1 INTERFERENCE MITIGATION TECHNIQUES FOR FUTURE SYSTEMS PLANNING TO OPERATE IN THE 2200-2290 MHZ BAND
Document status		Published
Relevant resolution	*SFCG*	SFCG RES 27-1 NTERFERENCE MITIGATION TECHNIQUES FOR FUTURE SYSTEMS PLANNING TO OPERATE IN THE 2025-2110 MHZ BAND
Document status		Published
Relevant resolution	*SFCG*	SFCG RES 17-1R2 Protection of Space Science Services from Terrestrial Service Systems in the Band 2025-2110 MHz and 2200-2290 MHz
Document status		Published

Finding 4. Protection of the 8 GHz Band

Relevant recommendation	*ITU-R*	ITU-R Rec. SA.1810-1 System design guidelines for Earth exploration-satellites operating in the band 8 025-8 400 MHz
Document status		Published
Relevant recommendation	*SFCG*	SFCG REC 14-3R10 USE OF THE 8025-8400 MHz BAND BY EARTH EXPLORATION SATELLITES
Document status		Published (similar recommendation is published as ITU-R Rec. SA.1810-1)
Relevant recommendation	*SFCG*	SFCG Rec 12-4R3 Methods For Reduction of Potential Interference Between Systems in the Space Science Services in Densely Occupied Bands
Document status		Published
Relevant recommendation	*SFCG*	SFCG Rec 18-2 Minimum Earth Station G/T Requirements for Reception of Non-Geostationary EESS in the 8025-8400 MHz Bands
Document status		Published
Relevant recommendation	*SFCG*	SFCG REC 21-2R4 Efficient Spectrum Utilisation for Space Research Service (Category A) and Earth Exploration-Satellite Service on Space-to-Earth Links
Document status		Published

Finding 5. Protection of the 26 GHz Band

Relevant recommendation	*ITU-R*	ITU-R Rec. SA. 2142, Methodologies for calculating coordination zones areas around Earth exploration satellite and space research earth stations to avoid harmful interference from IMT-2020 systems in the frequency bands 25.5-27 GHz and 37-38 GHz
Document status		Published
Relevant recommendation	*ITU-R*	ITU-R Rec. SA.1862 Guidelines for efficient use of the band 25.5-27.0 GHz by the Earth exploration-satellite service (space-to-Earth) and space research service (space-to-Earth)
Document status		Published
Relevant recommendation	*SFCG*	SFCG REC 29-1 Efficient Sharing of the 25.5 - 27.0 GHz Band between EESS (s-E) and SRS (s-E)
Document status		Published (same recommendation is published as ITU-R Rec. SA.1862)
Relevant recommendation	*SFCG*	SFCG REC 30-2 Efficient Use of the 25.5 - 27.0 GHz Frequency Band by Future Earth Exploration-Satellite Systems and Space Research Satellite Systems
Document status		Published
Relevant recommendation	*SFCG*	SFCG REC 21-2R4 Efficient Spectrum Utilisation for Space Research Service (Category A) and Earth Exploration-Satellite Service on Space-to-Earth Links
Document status		Published

Finding 6. Increasing difficulties of frequency coordination and avoidance of interferences

Relevant ITU-R resolution	Resolution 32 (WRC-19) Regulatory procedures for frequency assignments to non-geostationary-satellite networks or systems identified as short-duration mission not subject to the application of Section II of Article 9
Document status	Published
Relevant ITU-R Radio Regulation	ARTICLE 11; Notification and recording of frequency assignments, provision 11.49 ARTICLE 22; Space services; provision 22.1
Document status	Published, Edition 2020

Finding 7. Coordination on the downlink times

Relevant SFCG recommendation	SFGC 12-4R3 Methods for Reduction of Potential Interference between Systems in the Space Science Service in Densely Occupied Bands
Document status	Published
Relevant SFCG resolution	RES A12-1R3 Establishment of Procedures for Interagency Frequency Coordination
Document status	Published

References

[1] Soula, Jean-Marc & Liebrecht, Philip & Pilgram, Martin & Walker, Jon & Costrell, James & Calzolari, Gian-Paolo & Hell, Wolfgang. (2012). The Interagency Operations Advisory Group (IOAG) A decade of leadership in International Space Cooperation.

[2] Space Operations Sustainability (SOS) Working Group, Report Issue A, 2 Mar 2021, https://www.ioag.org/Public%20Documents/IOAG.SOSWG.RPT.2021.v1.pdf

[3] Space Operations Sustainability (SOS) Working Group, Report Issue B, 25 May 2022, https://www.ioag.org/Public%20Documents/SOSWG%20report%20B.pdf