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IOS SPECTRUM REQUIREMENT AND RELATED STUDIES UNDER RESOLUTION ITU-R 74 (RA-23)

To support the ongoing work on sustainable use of the radio-frequency spectrum and associated satellite-orbit resources, the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) has prepared a report on the current development and spectrum usage of In-Orbit servicing (IOS), also known as In-space Servicing, Assembly, and Manufacturing (ISAM) activities. The report provides technical information and constraints, operational scenarios, and proposals to assist studies in line with Resolution ITU-R 74 (RA-23, Dubai 2023), addressing the radiocommunication requirements of IOS/ISAM to ensure their safe, efficient and sustainable implementation which will actively contribute to space sustainability.

Proposal

This contribution proposes initiating work within Study Group 4 to prepare a new ITU-R Report in Annex 1 and a new Question and related studies in Annex 2, providing a consolidated technical basis for timely consideration in line with the sustainability goals of Resolution ITU-R 74 (RA-23) and the principles of Article 44 on rational, efficient use of spectrum and associated orbits.

Attachment: 1

ATTACHMENT

1 Introduction

In-Orbit Servicing (IOS), also known as In-space Servicing, Assembly, and Manufacturing (ISAM) or just satellite servicing, refers to cooperative operations in which one space object provides services to another while either docked together or operating in close proximity. These services include satellite life extension, refueling, active debris removal, inspection, and in-space assembly and manufacturing, among others. IOS has progressed from early demonstrations to initial commercial operations in both geostationary (GSO) and non-geostationary orbits (NGSO) and is emerging as a critical capability to support the long-term sustainability of space activities and the growing space economy.

As directed by Plenipotentiary Conference Resolution 219 (Bucharest, 2022), the Radiocommunication Assembly 2023 launched a series of efforts pertaining to improving the sustainability of the radio-frequency spectrum and associated satellite-orbit resources. These efforts are described in Resolution ITU-R 74 (RA-23) which were later supported by the World Radiocommunication Conference 2023. IOS directly advances these objectives by extending satellite lifetimes, resolving satellite anomalies, mitigating new orbital debris generation, and remediating existing debris. By reducing collision and fragmentation risk and improving operational predictability, IOS helps in mitigating technical, operational, and coordination burdens for current operators and new entrants. These outcomes also align with Article 44 of the ITU Constitution, which identifies radio-frequency spectrum and associated orbits as limited natural resources and requires their rational, efficient, and economical use to ensure equitable access for all Member States.

Despite the growing role of IOS, the Radio Regulations do not currently contain provisions tailored to its unique radiocommunication requirements. Current practice relies on case-by-case use of existing allocations, such as those for the space operation service (SOS) and the space research service (SRS), which were not designed with IOS-specific needs in mind. This approach creates uncertainty for administrations and operators, complicates coordination, and poses challenges for ensuring predictable access to spectrum and protection of incumbent services.

Given the safety-critical nature of IOS links for rendezvous, proximity operations (RPO), docking, and contingency maneuvers, there is an urgent need for ITU-R to study this matter. These studies should characterize IOS radiocommunication requirements, examine sharing and compatibility with incumbent services, and develop the technical basis for their safe operation. This work directly addresses the sustainability-focused studies called for in Resolution 219 (Bucharest, 2022) and is undertaken pursuant to Resolution ITU-R 74 (RA-23), which reinforces sustainable use of spectrum and orbits and explicitly references IOS.

2 Overview of In-Orbit Servicing Missions

In-orbit servicing (IOS) has advanced significantly over the past two decades and has now demonstrated multiple operational applications across orbital regimes. Initial governmental servicing missions have been conducted since the late 1990s, with spacecraft such as JAXA’s KIKU-7 demonstrating autonomous RPO and docking. Since that time, IOS has progressed through both governmental and commercial initiatives into an operational reality.

In the geostationary orbit, satellite life extension has been demonstrated by commercial providers. Mission Extension Vehicle-1 successfully docked with Intelsat-901 in 2020 and has continued to provide station-keeping services. Mission Extension Vehicle-2 subsequently docked with Intelsat-1002 in 2021. These missions proved that IOS can extend satellite lifetimes, delay replacement launches, and improve cost and spectrum efficiency for operators. Additional commercial missions are currently in development to provide refueling and relocation services in geostationary orbit.

In non-geostationary orbit, multiple actors have conducted inspection and active debris removal (ADR) development IOS missions. The European Commission's Remove DEBRIS mission and Japan's ELSA-d and ADRAS-J mission have demonstrated technologies for debris rendezvous and capture. Additional commercial operators have announced and, in some cases, secured government contracts to conduct IOS missions involving debris capture, relocation, and end-of-life disposal.

The scope of IOS has also broadened to include ISAM. Demonstrations aboard the International Space Station have shown the feasibility of additive manufacturing and assembly in microgravity. Concepts for free-flying manufacturing platforms have advanced into funded development. These activities expand IOS beyond the servicing of legacy satellites into new sustainable architectures that are more mass-efficient and help establish circular economies.

Taken together, this history of demonstrated missions, ongoing government contracts, and increasing private sector participation confirms that IOS is a proven capability with clear applications, operational heritage, and significant near-term potential. A comprehensive and enduring solution is therefore urgently needed to provide regulatory certainty and equitable spectrum access for IOS, while also ensuring its growth is compatible with incumbent services and aligned with the Radio Regulations.

3 Growing Role of IOS in Space Sustainability

Space sustainability refers to ensuring the safety and long-term viability of space activities so that the space environment remains suitable for exploration and use by the current and future generations of all countries. IOS contributes to this goal by offering a suite of technologies, services, and applications that directly address challenges to space sustainability. Services such as refueling, orbital relocation, detumbling, life extension, and inspection enhance the safety and function of operational assets as well as the mitigation and remediation of orbital debris. Such outcomes support the equitable, rational, and efficient utilization of spectrum and orbit resources and aligns IOS with the objectives of Resolution ITU-R 74 (RA-23).

Other ways in which IOS capabilities directly contribute to space sustainability include:

- Orbital Debris Remediation: RPO capabilities, as well as grappling and docking technologies, enable space debris remediation and removal.

- Enhanced End-of-Life Disposal: IOS providers have developed interfaces which, when included on spacecraft, can serve as enablers for mitigation of debris under anomalous conditions such as control failures or fuel outages. Services such as refueling, life extension, and relocation enable operators with prepared spacecraft to comply with disposal or maneuverability requirements even under anomalous conditions.

- More Efficient Use of Orbital and Spectrum Resources: IOS contributes to more effective use of orbital and spectrum resources through services such as life extension of existing satellites, and orbital relocation and transfer capabilities. The ability to relocate satellites, enhance station-keeping capabilities, and address anomalies can increase spectrum utilization and reduce and mitigate harmful interference.

- Space Situational Awareness: IOS capabilities contribute to space situational awareness (SSA) via non-Earth imaging capabilities and services, such as tracking and inspection, which help characterize debris objects, diagnose spacecraft anomalies, and guide safe RPO.

The growth of IOS technologies and services to extend the efficiency and operational lifetimes of client satellites also expands the toolkit of options for satellite operators to mitigate and remediate orbital debris, even in the event of anomalies or other unforeseen circumstances. In tandem with other satellite design approaches, the development and adoption of common inter- and intra-system interfaces, such as those for docking and exchange of fuel, power, and data, will accelerate the ability of spacecraft operators and manufacturers to design and operate spacecraft that are prepared for servicing in advance. Such practices and interfaces can be also designed to be compatible with removal from orbit and help to facilitate reuse or recycling.

4 Policy Context and Regulatory Drivers for IOS Development

Over the last decade, an increasing number of international consortia, national regulators, and intergovernmental bodies have developed guidelines, policies, and initiatives in response to the urgent issue of space sustainability. These efforts primarily focus on the risk posed by orbital debris, the accumulation of which threatens our long-term ability to utilize space. A significant portion of global socio-economic activities, including agriculture, transportation, banking, weather-forecasting (*inter alia*), and communication, depend on space assets and their predictable operation. The uncontrolled growth of orbital debris could have enormous impacts on the modern world should it prohibit the equitable and efficient access to these essential capabilities.

Space sustainability guidelines, at both national and global levels, therefore, play a critical role in highlighting the urgency of this issue and fostering alignment around how to act collectively. For example, at the national level, the United States Federal Communications Commission (FCC) has adopted a five-year post-mission disposal requirement for NGSO satellite constellations and has also enforced GSO disposal rules through penalties for non-compliance. At the global level, the UN COPUOS Guidelines for the Long-Term Sustainability of Outer Space Activities provide multiple recommendations to work towards sustainability goals. Importantly, the guidelines also encourage States to promote programs and technologies in support of achieving these goals.

Among the technologies aligned with these sustainability goals is IOS, which directly supports compliance with guidelines by providing capabilities that can mitigate and remediate debris risks, decrease orbital decay times, and extend the useful life of space assets. As such, IOS is increasingly recognized not only as a technical solution but also as a policy-relevant tool for implementing long-term sustainability frameworks. In line with this, the European Commission has drafted regulations[1] which, along with mandatory debris mitigation planning, requires provisions to facilitate IOS. The Inter-Agency Space Debris Committee (IADC) also agreed that additional measures, such as enabling technology for ADR, are needed to complement strict compliance with guidelines[2]. Such policies explicitly supporting IOS can help bridge the gap between aspirational guidelines and actionable outcomes.

The ITU also acknowledges the need to address the most pressing challenges in space sustainability by organising the annual Space Sustainability Forum, the first one in September 2024 and the second one in October 2025, which brings together global leaders and experts to focus on managing satellite constellations, advancing sustainable exploration from LEO to Lunar, and achieving an effective Space and Spectrum Situational Awareness (S3A) as a key element for mission success, security, and sustainability of space radiocommunications systems. During the proceedings, IOS was recognised as a critical capability to support the sustainability of space activities.

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[1] EU Space Act - https://defence-industry-space.ec.europa.eu/eu-space-act_en

[2] IADC Report on the Status of the Space Debris Environment (Issue 3, January 2025).

5 Current Status of Spectrum Use for IOS Activities

The ITU Radio Regulations (RR) do not currently include any specific provision for IOS as a separate radiocommunication service. As a result, there are no internationally agreed rules on spectrum usage for IOS services, whether for its overall operations or for specific functions such as telemetry, tracking and command (TT&C) or sensor data downlink.

IOS missions currently rely on existing allocations made to the space operation service and the space research service. These allocations have enabled initial demonstrations, generally under experimental or mission-specific licensing frameworks. However, it remains unclear whether the full scope of IOS activities is consistent with the definitions of either SOS or SRS as defined in the RR. Moreover, commercial IOS missions that involve servicing a third-party spacecraft are unlikely to qualify for such allocations in practice. As a result, SOS and SRS allocations, as currently defined, may not provide a sustainable long-term basis for licensing IOS missions.

Further analyses on these and other issues related to spectrum allocations are provided in Annex 3.

6 Justification for Recognized Spectrum for IOS

Compared to other space activities, IOS missions typically have a higher proportion of critical phases throughout their timelines, with more complexity and carrying more substantial failure consequences. The nature of navigating two space objects into close proximity to one another requires an increased level of monitoring to enable safe operations and timely intervention if needed.

As a result, IOS missions require a unique set of operational capabilities to ensure safety, reliability, and mission success, particularly during RPO, which may include docking and servicing. These phases demand precise relative navigation, continuous situational awareness, Go/No-Go decision-making, and sometimes interventions or aborts based on real-time data and risk assessment.

These needs and other technical aspects of IOS missions are further explored in Annex 4.

7 Conclusion

While the goals of advancing space sustainability are directly supported by IOS capabilities, the IOS sector currently lacks the clear spectrum recognition and regulatory certainty required for its safe execution and sustained growth. Timely action by the ITU-R, including the consideration of what is proposed in the annexes of this contribution, will be essential to enable these critical capabilities, safeguard existing radiocommunication services, and advance the long-term sustainability of space activities in line with Resolution ITU-R 74 (RA-23) and Article 44 of the ITU Constitution.

Annex 1: Working document towards a Preliminary Draft New Report ITU-R S.[IOS CHAR] - Characteristics of in-orbit servicing (IOS) and spectrum requirements to support their safe operation

1 Introduction

This Report examines the spectrum requirements and regulatory considerations for in-orbit servicing (IOS) systems, including missions in GSO and non-GSO orbits. It addresses the technical and operational characteristics of IOS, spectrum needs across mission phases, the adequacy of current frequency allocations and limitations of existing regulatory provisions. This report also considers IOS communication system architectures, frequency bands, and sharing and compatibility with incumbent services, including potential protection criteria.

2 Scope

The scope of this Report is to:

a) describe the technical and operational characteristics of IOS missions in GSO and non-GSO orbits, including mission phases and associated radiocommunication links;
b) identify IOS spectrum requirements across mission phases and orbital regime, addressing bandwidth, data rates, latency and link reliability required for safe operations;
c) assess the adequacy of the frequency bands currently used on an ad hoc basis and their suitability for long-term commercial IOS operations;
d) assess the technical and regulatory limitations of existing allocations with respect to IOS operational requirements;
e) identify the IOS communication system architecture, including direct to Earth communication, space-to-space proximity operations and potential use of inter-satellite links;
f) assess the adequacy of existing allocations and if necessary, identify other frequency bands that could potentially support IOS operations and study sharing and compatibility with existing in-band and adjacent band services, including the development of appropriate protection criteria.

3 Structure of the Report

3.1 Introduction and Scope
3.2 Background (e.g., IOS missions and their role in advancing space sustainability, growth forecast of IOS activities in LEO, MEO, and GEO)
3.3 Technical and Operational Characteristics of IOS
3.4 Spectrum Requirements for IOS
3.5 Communication System Architecture for IOS
3.6 Assessment of Existing Spectrum Allocations
3.8 Frequency bands that could support operations and associated sharing and compatibility studies
3.9 Conclusions

4 Expected outcomes

The Report will provide a technical basis for Member States and other members to understand IOS spectrum-related requirements and sharing considerations, with interim outputs available to inform deliberations at WRC-27.

Annex 2: (Preliminary) Draft New Question ITU-R [SG 4/IOS] - Studies on radiocommunication characteristics, spectrum needs, and sharing considerations for in-orbit servicing (IOS)

The ITU Radiocommunication Assembly,

recalling

a) Resolution ITU-R 74 (RA-23), which instructs relevant Radiocommunication study groups to conduct studies towards the development of a new Recommendation providing guidance on safe and efficient deorbit and/or disposal strategies and methodologies for non-GSO space stations involved in radiocommunication services after the end of their life, focusing on the radio-frequency spectrum and associated satellite-orbit resources used by space services, and considers the development of in-orbit servicing (IOS) as a relevant technology;

noting

a) that IOS capabilities can directly enable safe and efficient disposal strategies for non-GSO space stations, support adherence to Recommendation ITU-R S.1003-2 for GSO space stations, and mitigate debris risks, improving long-term sustainability of spectrum and associated satellite-orbit resources;

considering

a) that IOS is evolving beyond experimental missions into commercial operations with increasing demand for spectrum;

b) that the Radio Regulations do not currently include any specific provision for IOS as a separate radiocommunication service and as a result there are no internationally agreed rules on spectrum usage for this application;

c) that it is necessary to establish criteria under which IOS can be accommodated within the radiocommunication services and to carry out relevant sharing and compatibility studies;

d) that in order to carry out these studies, protection criteria for existing and future planned systems need to be known, but there are no relevant Reports, Recommendations, or studies that provide implementation or protection criteria for IOS;

e) that IOS requires spectrum for telemetry, tracking, and command (TT&C) for routine maintenance spacecraft health as well as sensor data during safety-critical phases such as rendezvous, proximity operations, and docking;

f) that IOS missions currently rely on allocations in the space operation service (SOS) and the space research service (SRS) on an ad hoc basis, and that such allocations may not provide a sustainable regulatory framework for commercial IOS operations;

decides that the following Questions should be studied

1 What are the technical and operational characteristics of IOS, including those in GSO and non-GSO, that are relevant to spectrum use?

2 What are spectrum requirements of IOS systems across mission types, phases, and orbital regimes?

3 What protection criteria should be developed to support sharing and compatibility between IOS and other existing and planned services?

further decides

1 that the results of the above studies should be included in Recommendations and/or Reports;

2 that the above studies should be progressed under Study Group 4, with interim outputs provided as available, to inform deliberations at WRC-27 and subsequent work in the following study period.

Annex 3: Current Allocations Utilized by IOS and Associated Challenges

1 Existing Allocations Utilized by IOS (TT&C, ISL, Payload Communications)

In the technology demonstration phase, IOS applications may be considered as scientific or technological research activities, thereby justifying the use of frequency bands allocated to the Space Research Service (SRS). To date, IOS demonstration missions have employed various bands such as SRS (8450-8500 MHz) for sensor data downlink and the Space Operation Service (SOS) (2025-2110 MHz / 2200-2290 MHz) for telemetry and telecommand (TT&C).

In addition, several other frequency bands in various radiocommunication services allocations were also proposed to be used. This includes the use of 1525-1559 MHz and 1626.5-1660.5 MHz for inter-satellite links (ISL), the 8 GHz in the Earth-Exploration Satellite Service (EESS), and the 9 GHz in the Radiodetermination-satellite service (RDSS), supporting various mission functions in the planned demonstration missions.

The issue of addressing possible regulatory provisions for NGSO IOS systems, in particular with respect to TT&C transmissions, sensor links, and sensor feeder links was raised during the May 2022 meeting of WP4A in the last WRC-23 preparatory cycle under Topic L of Agenda Item 7. However, in the absence of technical sharing studies, the matter was concluded as No Change.

Subsequently, as reflected in Chairman’s Report of WP 4A (September 2022), the BR clarified that:

“Following discussions within WP 4A, the ITU-BR indicated that satellites providing in-orbit services can downlink data gathered through on-board sensors operating in other radiocommunications services through feeder links (see RR No. 1.115) operating in the FSS as per RR No. 1.21. It was also clarified that, as a consequence of this use of the FSS, such satellites may carry out TT&C operations in frequency bands allocated to the FSS, as indicated in No. 1.23 of the Radio Regulations.”

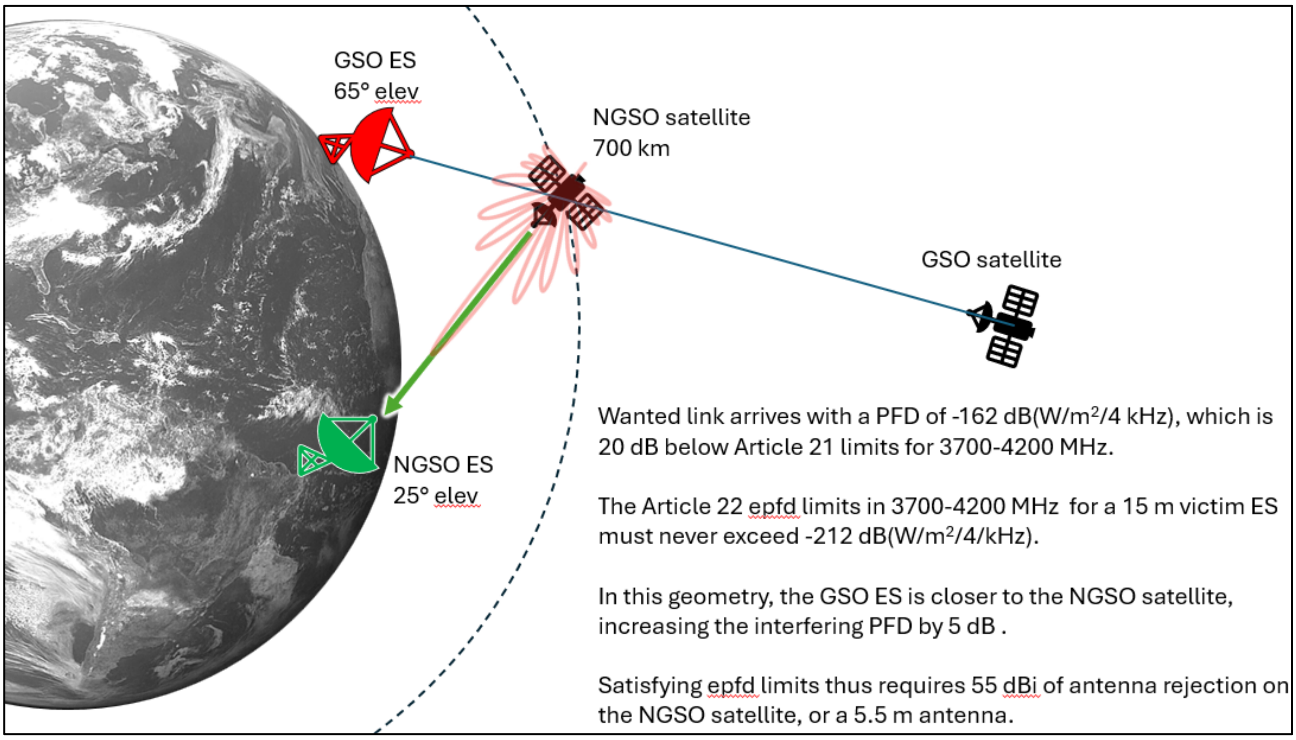
While these clarifications provide preliminary direction on the potential use of FSS bands for IOS applications, the spectrum in FSS is already extensively utilized for commercial satellite communications and subject to significant constraints. Accordingly, further study would be required to assess the compatibility and feasibility of utilizing frequency bands allocated to the FSS for IOS applications. This is further discussed in section 2.

2 Gaps and Limitations of the Current Allocations

The Radio Regulations allow IOS missions to make use of the fixed-satellite service (FSS) allocations. However, this approach has not been implemented to date and presents significant regulatory and technical challenges. Under Article 22, equivalent power flux-density (epfd) limits apply to all NGSO systems operating in the most used FSS allocations, including those consisting of a single servicing spacecraft. Compliance with these limits is typically achieved by using exclusion zones for the non-GSO link geometries. Despite these exclusion zones, NGSO constellations can provide uninterrupted service to earth stations by utilizing satellite diversity. For IOS missions with a single servicer, however, such exclusion zones result in communication interruptions which are highly disruptive during critical phases of IOS missions, such as rendezvous and docking, when continuous and interference-free telemetry, tracking and command are required for minimum safety.

In particular, compliance with epfd thresholds in 3700-4200 MHz would require impractically large antennas on servicing spacecraft. As shown in figure 1 below, where the wanted link is conservatively assumed to be 20 dB below the Article 21 power flux-density limits and large exclusion angles are employed, the 100% epfd threshold still requires an antenna rejection equivalent to an aperture of 5.5 meters on the servicing spacecraft. Such antennas are incompatible with IOS requirements, which rely on agile maneuverability and omni-directional communications during 6-degree-of-freedom proximity operations. FSS bands in 10.7 GHz and above are heavily occupied by incumbent NGSO systems with sharing requirements that also constrain omni-directional communications. Though GSO protection is less strict in these bands, exclusion zones and highly directional antennas are still required for wanted links. These factors likely render FSS allocations currently unsuitable for IOS.

Figure 1: Issues Caused by epfd Geometry



Wanted link arrives with a PFD of -162 dB(W/m^2/4 kHz), which is 20 dB below Article 21 limits for 3700-4200 MHz.

The Article 22 epfd limits in 3700-4200 MHz for a 15 m victim ES must never exceed -212 dB(W/m^2/4/kHz).

In this geometry, the GSO ES is closer to the NGSO satellite, increasing the interfering PFD by 5 dB .

Satisfying epfd limits thus requires 55 dBi of antenna rejection on the NGSO satellite, or a 5.5 m antenna.

In some cases, IOS missions could potentially operate under the provisions of No. 4.4 of the Radio Regulations, which allow administrations to authorize stations to operate on a non-protected, non-interference basis. In addition to determining that the intended use of the frequency assignment to the station under No. 4.4 will not cause harmful interference into the stations of other administrations operating in conformity with the Radio Regulations, the Regulations also require provision of measures that would be taken in order to comply with the requirement to immediately eliminate harmful interference. While this approach could provide a temporary path for certain short-term missions, it would still leave IOS without a recognized regulatory status. Operations under No. 4.4 must cease if harmful interference is caused, creating uncertainty for administrations and operators. This situation is not compatible with safety-critical activities within IOS, such as RPO, where predictable and protected communications are essential.

The current allocations available to IOS are either temporary, unsuitable for commercial operations, or impose technical constraints that make operations impracticable and unsafe. This demonstrates the need for further ITU-R studies to assess IOS spectrum requirements and to explore other frequency bands that could support IOS operations.

Annex 4: Additional Justification for Recognized Spectrum for IOS

1 Operational Needs and Risk Management

The key operational needs of IOS missions include:

- Accurate Relative Positioning: Determining and maintaining precise spatial relationships between the servicer and client objects.
- Sensor Data Acquisition and Client Analysis: Collecting, validating, and interpreting data from onboard sensors to characterize the client state, as well as to detect anomalies or deviations from expected behaviour.
- Trajectory Planning and Adjustment: Designing and refining safe approach paths to minimize risk, including iterative checks and contingency planning.
- Timely Response Capability: Rapidly reacting to emerging risks or unexpected conditions to preserve mission integrity and safety.

These functions rely on operators and ground systems having reliable and timely access to onboard data and unfettered ability to intervene when necessary. Accordingly, IOS missions require robust communication links that enable the following:

1. Intensive Monitoring: The ability to trend onboard activities and assess client status in near-real-time to ensure accurate and holistic situational awareness and mission continuity.
2. Robust Command Access: The ability to send commands for timely intervention when required.

These communication requirements must also be met without imposing constraints on the servicer's pointing capabilities, which are driven by the need to continuously track the client object with its onboard sensors. This limitation may reduce the number of compatible frequency allocations given the physical and coordination challenges introduced by omni-directional communication requirements.

2 Impact of Communication Gaps and Interference on Mission Safety

As noted in the previous section, IOS operations rely on intensive monitoring and robust access to maintain situational awareness and perform tasks within defined safety margins. These functions are essential not only for safe RPO but also for meeting regulatory and licensing obligations, which, under nascent frameworks, often impose highly precautionary constraints. When communication windows are degraded or uncertain, whether due to regulatory constraints, interference, or other factors impacting availability, operators must adopt more conservative procedures, including extended hold points and stringent abort criteria, which increase operational complexity and cost and may delay mission timelines.

This sensitivity is a key differentiating factor of IOS communications. Unlike some other space services, where temporary outages primarily affect data delivery, interruptions to IOS communications introduces risk during time-sensitive scenarios such as proximity operations, capture sequences, and contingency actions. While IOS systems incorporate autonomy and safeguards to manage expected delays or brief losses, predictable and protected communications reduce the need for excessive safety margins and enable more efficient execution of these phases. Clear and predictable access to appropriately allocated spectrum, with defined objectives for availability, continuity and integrity and suitable interference-protection criteria, mitigates these risks and supports safe execution of IOS phases in all relevant orbital regimes, consistent with the objectives of Resolution ITU-R 74 (RA-23).

3 Enabling Compliance with Debris Mitigation and Sustainability Policies

Existing policies and guidelines for space sustainability put strong emphasis on addressing the risk of generating new orbital debris. While operators may design their spacecraft and systems to adhere to these policies in nominal conditions, some anomalous scenarios may prevent compliance and put the environment at risk. In such scenarios, IOS can play a pivotal role in enabling compliance, thus maintaining the desired outcomes of the enacted policies.

Policies and guidelines addressing orbital debris generally focus on two complementary aspects, mitigation and remediation, and IOS is essential for achieving both. Debris mitigation entails avoiding the creation of new debris. This can be done through reducing the probability of in-orbit collisions and break-ups, and conducting timely post-mission disposal (PMD). In-orbit collisions with other space assets or pieces of debris can be prevented through relying on accurate Space Situational Awareness, detecting high-risk conjunctions, and performing collision avoidance maneuvers when necessary. However, if both objects involved are non-manoeuvrable, IOS may become a necessity to avoid a collision. There are existing international standards for debris mitigation and many States have put in place national policies or regulations implementing them, although the rate of compliance is still low.

Debris remediation comprises the removal of large debris objects already in orbit. This can be achieved through Active Debris Removal (ADR) services, which capture and remove debris objects, whether they are rocket bodies, non-functional spacecraft, or pieces of debris resulting from previous break-up events. Several development programmes are under way at the international level, including the European Space Agency’s ClearSpace-1 and Capture Payload Bay (CAT) missions, UKSA’s ELSA-M and COSMIC missions, as well as JAXA’s Commercial Removal of Debris Demonstration programme (CRD2) encompassing the ADRAS-J1 and -J2 missions.

For timely PMD in LEO, in cases where natural orbital decay times are unacceptably long, satellite operators can employ propulsion, drag augmentation, solar sails, or electrodynamic tethers. These technologies help to ensure compliance with applicable requirements and guidelines. However, because such spacecraft rely on the successful operation of these methods, and a failure of one or more components may prevent compliance, IOS can provide an important backup means for complying with PMD requirements.

In GSO, operators must rely on propulsion to dispose of their satellites in the graveyard orbit, in compliance with Recommendation ITU-R S.1003. There are two limitations to such a strategy. Firstly, fuel is often the primary limiting factor on a satellite’s lifetime, and reserving fuel for end-of-life disposal can reduce the potential lifetime of assets that would otherwise remain functional. Second, if a critical system fails, end-of-life disposal may become impossible. IOS can address both limitations by docking with a client satellite and either providing refueling services or performing the disposal maneuvers for the client. This not only allows GSO assets to operate for longer periods of time, thus increasing spectrum usage efficiency, but also enables safe post-mission disposal.

IOS can also foster the emergence of an in-space circular economy which, while not explicitly reflected in current policies, would enable recycling, refurbishment, and reuse of materials, supporting safer and more sustainable methods to comply with disposal and re-entry regulations. As such, IOS is not only crucial for enabling full compliance with existing sustainability policies but may also be instrumental in the establishment of a more sustainable space ecosystem overall. It is therefore essential to ensure that spectrum allocations and operational licensing frameworks allow for the safe and effective performance of such operations.

4 IOS Application Scenarios and Corresponding Spectrum Needs

4.1 Case Study 1: GSO Satellite Life Extension and/or Refueling

Satellite life extension and refueling missions in GSO represent some of the earliest and most commercially mature applications of IOS. Notable examples include the aforementioned MEV series, which has successfully docked with and extended the life of multiple GSO satellites; the planned United States Space Force APS-R mission, which will demonstrate refueling of GSO assets; and the European Space Agency's planned RISE mission, which aims to extend the operational life of satellites in the geostationary regime through robotic servicing. Collectively, these missions highlight the global momentum toward sustainable GSO operations and underscore the increasing technical and regulatory demands for robust, reliable communications and spectrum access throughout all phases of life extension and refueling activities.

The mission profile for GSO life extension and refueling is characterized by several distinct phases, each with specific communications and spectrum requirements. During launch and early operations, routine telemetry, tracking, and command (TT&C) links are established to verify spacecraft health and initiate orbital adjustments. As the servicer approaches the client satellite, long-range rendezvous operations rely on absolute navigation and regular TT&C updates, typically supported by a few ground stations passes per day.

Once proximity operations commence, the servicer transitions to relative navigation and prepares for docking. At this stage, it is critical to characterize the client's tumbling rate. If the rotation is minor, the servicer may synchronize or match the rate; if excessive, detumbling strategies, including non-contact methods such as laser-based techniques or plume impingement, must be employed to stabilize the target before approach. This phase demands continuous situational awareness, precise control, and real-time command capability to ensure safe approach and successful mechanical docking. Payload data downlink requirements increase as high-resolution imagery and sensor data are transmitted to the ground for analysis and verification of docking procedures. Minimizing communications gaps during these critical operations is essential, and operators may leverage multiple ground stations to maintain near-continuous contact.

Following successful docking, the servicer may perform station-keeping, refueling, or orbital relocation. These activities require sustained TT&C links to monitor system status, execute maneuvers, and ensure the safety of both spacecraft. The ability to intervene rapidly in case of anomalies remains paramount throughout the mission. Upon completion of servicing, the servicer may undock and depart, concluding the mission with routine TT&C coverage.

Throughout all phases, robust and reliable communications are required to maintain positive control, support contingency operations, and ensure mission safety. The cadence and bandwidth of communications links vary according to operational needs, with the most stringent requirements arising during proximity operations and docking.

The following table summarizes the communications requirements by mission phase, including duration, pass frequency, bandwidth needs, and the importance of minimizing communications gaps:

Summary Table: GEO Life Extension Communications Needs by Mission Phase

Mission Phase	Duration	Comms Passes/ Day	Bandwidth Need	Criticality	Gaps/Continuity Requirement
LEOP & Commissioning	Days	A few	Moderate	High	Moderate (routine ops)
Long-Range Rendezvous	Weeks	A few	Low	Moderate	Moderate (routine ops)
Proximity Approach	Days	Several tens	High	Very High	Minimize gaps (critical ops)
Docking	Days	Several tens	High	Very High	Near-continuous, (critical ops)
Stationkeeping/ Refueling/ Relocation	Weeks to Years	Many	Moderate	High	Minimize gaps (critical ops)
Departure/ Undocking	Days	A few	Moderate	Moderate	Moderate

Note*: "Gaps" refers to periods without ground contact. During critical phases, operations are planned to minimize these gaps, often by using multiple ground stations and scheduling key maneuvers during periods of continuous visibility.*

In summary, GEO satellite life extension and refueling missions demand resilient, high-availability communications throughout all mission phases, with particularly stringent requirements for bandwidth, continuity, and reliability during close approach, docking, and servicing operations. Spectrum access and ground station coordination are essential to mission safety and operational success.

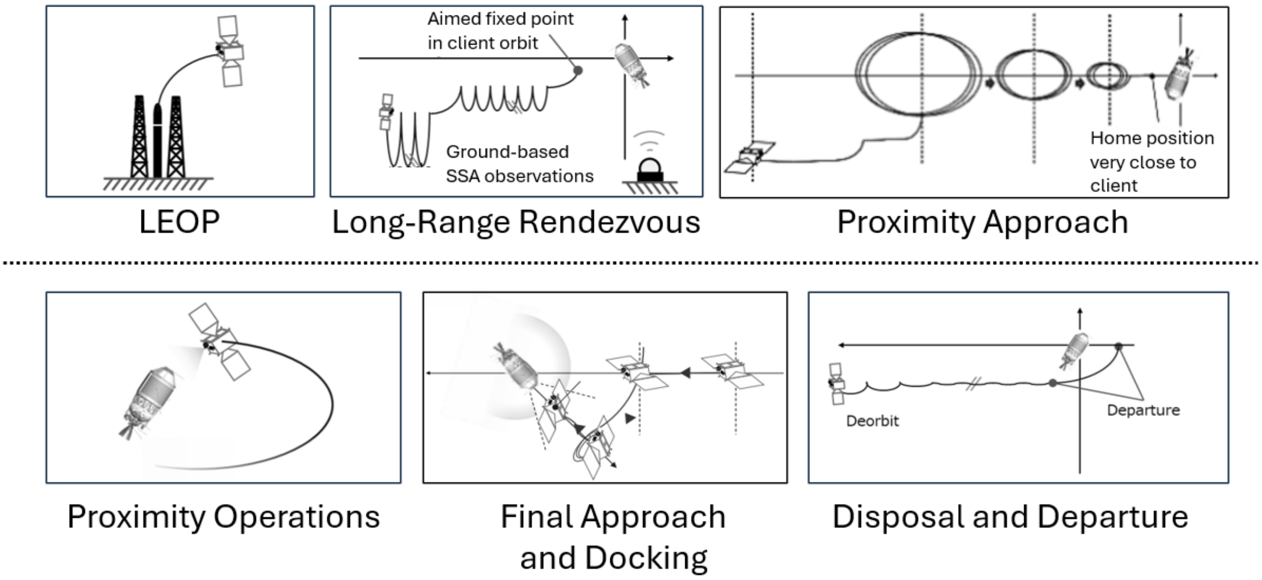
4.2 Case Study 2: Active Debris Inspection and Removal

Active debris inspection and removal missions are designed to approach, inspect, dock with, and ultimately remove or dispose of large, non-cooperative objects in orbit. This emerging and rapidly maturing field is exemplified by a growing list of international demonstration and operational projects including JAXA's Commercial Removal of Debris Demonstration (CRD2) program with the ADRAS-J and ADRAS-J2 missions, which pioneered close-proximity inspection and are advancing toward full-scale debris removal; the ISSA-J1 program under the Japan Ministry of Education, Culture, Sports, Science and Technology (MEXT) for its Small and Business Innovation Research (SBIR) program to develop an on-orbit inspection mission that will image and diagnose two large, defunct satellites in space; ESA's ClearSpace-1, which aims to capture and deorbit a large piece of debris in low Earth orbit; the United Kingdom's COSMIC and ELSA-M missions, which are developing technologies for multi-client debris removal and servicing; Japan's non-contact, laser-based detumbling and removal mission, which seeks to demonstrate precision torque application and momentum reduction for stabilizing and safely disposing of small-large, uncooperative debris, and Australia’s MAITRI initiative, which will demonstrate remote inspection and debris characterization through staged proximity operations. Collectively, these missions reflect the global support of active debris remediation and inspection, highlighting the increasing technical and regulatory demands for robust, reliable communications and spectrum access throughout all phases of operation.

The missions are typically divided into several critical phases, as shown in figure 2, each with different communication needs:

- **Launch and Early Operations (LEOP):** Initial system checks and orbit determination using ground-based tracking and onboard GPS.
- **Long-Range Rendezvous:** The servicer maneuvers to align with the client object’s orbit, using absolute navigation based on ground observations.
- **Proximity Approach:** Transition to relative navigation using onboard sensors (visible cameras, infrared cameras, LiDAR) as the servicer closes in from several kilometers to within tens of meters of the client.
- **Proximity Operations:** Execution of close-ranged observations, collecting high-resolution imagery and characterizing the client object's condition, rotation, and attitude.
- **Final Approach, Docking and Control:** The servicer performs the final approach to the client object, executes docking or capture maneuvers, and establishes stable control over the combined system. At this stage, it is critical to characterize the client’s tumbling rate. If the rotation is minor, the servicer may synchronize or match the rate; if excessive, detumbling strategies must be employed to stabilize the target prior to capture. This phase may include attitude stabilization, securing mechanical interfaces, and verifying the safety of the joint configuration. Continuous monitoring and real-time command capability are critical, as is the ability to abort in case of anomalies.
- **Disposal and Departure:** The servicer initiates the disposal process, which may involve controlled deorbiting of the client object, transfer to a graveyard orbit, or other end-of-life maneuvers. After successful disposal, the servicer either deorbits itself or departs to a safe orbit to prepare for another removal.

Figure 2: ADR Mission Phases



Throughout these phases, robust and responsive communications are required to ensure mission safety and success. The cadence and bandwidth required for telemetry, tracking, and command (TTC) links and payload data depend on the mission phase as discussed below.

During LEOP and Long-Range Rendezvous, operations typically rely on consistent TTC updates, utilizing a few ground station passes per day. However, as the mission transitions to proximity approach, inspection, and docking, the need for near-continuous contact intensifies. During these critical phases, operators may secure up to 50 ground station passes per day across multiple ground stations worldwide, minimizing gaps between passes and enabling real-time decision-making.

Payload data downlink becomes especially important during inspection and docking as high-resolution imagery and other sensor data must be transmitted to the ground for analysis and planning. Extended loss of downlink windows can delay ground-based assessment and operational adjustments and introduces risk to mission safety as relative positions must be closely monitored.

While the servicer must be able to autonomously execute aborts if anomalies are detected, rapid ground intervention remains necessary for extraneous situations, overrides, and rapid recovery. Thus, reliable communications with minimal gaps are essential for safety and efficiency in time and fuel.

The following table summarizes the communications requirements by mission phase, including duration, pass frequency, bandwidth needs, and the importance of minimizing communications gaps:

Summary Table: ADR Communications Needs by Mission Phase

Mission Phase	Duration	Comms Passes/ Day	Bandwidth Need	Criticality	Gaps/Continuity Requirement
LEOP & Commissioning	Days	A few	Moderate	High	Moderate (routine ops)
Long-Range Rendezvous	Weeks to months	A few	Low	Moderate	Moderate (routine ops)
Proximity Approach	Weeks	Several tens	High	Very High	Minimize gaps (critical ops)
Inspection & Docking	Days to weeks	Several tens	High	Very High	Near-continuous, (critical ops)
Removal/Disposal	Months	Many	Moderate	High	Minimize gaps (critical ops)
Departure/Deorbit	Days	A few	Moderate	Moderate	Moderate

Note: *"Gaps" refers to periods without ground contact. During critical phases, operations are planned to minimize these gaps, often by using multiple ground stations and scheduling key maneuvers during periods of continuous visibility.*

In summary, active debris inspection and removal missions require robust, high-availability communications across all mission phases, with particularly stringent requirements for bandwidth, continuity, and reliability during close approach, and docking operations when the two space objects must be carefully managed to avoid collision. Spectrum access and ground station coordination are critical to mission safety and success.

4.3 Case Study 3: Other emerging applications such as In-Space Assembly and Manufacturing, Refurbishment, Multi-Client Servicing

Various other IOS applications have been studied or are now being actively pursued through international demonstration and development programs. Notable examples include NASA's OSAM-1 and OSAM-2 missions, which have advanced the field of in-space assembly and manufacturing; the European Commission's ISOS initiative, which is exploring upgradable constellation design; and other ongoing efforts in both the public and private sectors to enable modular, repairable, and reconfigurable space infrastructure.

While these emerging applications build on the core capabilities established previous IOS missions, they differ slightly in their operational timelines and communications profiles. In-space assembly and manufacturing projects, for example, are expected to require sustained high-bandwidth communications over extended periods, supporting continuous coordination between robotic systems and ground operators. However, the continuity of communications is generally less critical than in short-duration, high-risk phases such as docking or debris capture.

Multi-client servicing missions, which may involve a single servicer cycling through inspection, repair, or removal operations for multiple client satellites, largely replicate the communications and spectrum requirements of debris removal missions. The key distinction is the longer-term nature of these missions, as the servicer repeatedly transitions through approach, proximity, and servicing phases for several clients over the course of a single mission.

In summary, while the fundamental spectrum and operational needs of emerging IOS applications remain similar to those of established use cases, the extended duration and evolving mission architectures of assembly, manufacturing, and multi-client servicing will place new demands on bandwidth, link management, and regulatory frameworks as these activities mature.

5 Estimation of IOS Spectrum Demand and Sharing

As illustrated in the case studies of section 4, IOS links comprise a near-continuous TT&C baseline with modest throughput and high availability, overlaid by episodic sensor data transmissions that are relatively brief, time-critical, and higher in data-rate. In current operations, the instantaneous bandwidth needs for sensor data falls in the tens of MHz range, particularly during phases such as proximity operations, capture, control, and post-maneuver assessment. In other mission phases, the sensors are largely inactive, resulting in long intervals of minimal spectral demand.

In some bands commonly used for space operations, congestion controls can include frequency partition, such as limiting missions to 10 MHz, to mitigate crowding. While such partitioning is helpful, IOS missions inherently exhibit temporal partition, given that the high-bandwidth activity is short in duration and separated by extended intervals of lower-rate TT&C. Exploiting this time-domain occupancy can ease coordination to an equal or greater extent, since this sporadic nature of high-bandwidth communications reduces overall spectral loading. This characteristic of low-rate continuity and brief high-rate bursts under interference-protected, high-availability objectives forms the basis for IOS spectrum demand and its coordination.

6 Growth Forecast of IOS Activities in LEO, MEO, and GEO

This section provides an operator- and administration-neutral outlook on the anticipated growth of IOS. The outlook extends through 2040 and is intended to inform Member States, Sector Members, and Associates in their consideration of spectrum, safety-of-flight, and regulatory implications within ITU study groups. The assessment is grounded in authoritative market forecasts such as NSR's IoSM programme[3], regulatory frameworks including the U.S. Federal Communications Commission's 5-year LEO disposal rule [4], and recent demonstration missions.

6.1 Growth outlook by orbit (2025–2040)

Across all orbital regimes, the number of satellites is expanding at a rapid pace: in LEO, more than 74,000 satellites are planned, making it by far the largest growth domain; in MEO, more than 31 satellites are currently planned, mainly serving navigation and broadband functions; while in GEO, more than 76 active satellites are operated today across major fleets. These figures, while drawn from a few representative examples, are expected to grow further as new companies and organizations enter the market, underscoring the trend toward sustained and large-scale deployment across all orbital layers.

Orbit	Company / Entity	Approximate Number of Satellites Planned / Nominal
LEO	SpaceX – Starlink	~42,000 satellites planned; ~12,000 in first authorized phase[5]
	Amazon – Project Kuiper	3,236 satellites planned[6]
	Eutelsat OneWeb	648 satellites (first-generation full constellation) in LEO[7]
	European Union / ESA / SpaceRISE – IRIS²	264 satellites in LEO[8]
	China - Guowang	Over 13,000 satellites planned (split between lower and higher LEO altitudes)[9]

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[3] Global News Wire - NSR's In-Orbit Services Report Projects $14.3 Billion in Revenues as Non-Geo Constellations Grow Demand, *https://www.globenewswire.com/news-release/2022/02/15/2384849/0/en/NSR-s-In-Orbit-Services-Report-Projects-14-3-Billion-in-Revenues-as-Non-Geo-Constellations-Grow-Demand.html*

[4] Federal Communications Commission. *FCC Adopts New Space Debris Mitigation Rules https://docs.fcc.gov/public/attachments/FCC-22-74A1_Rcd.pdf*

[5] How Many Starlink Satellites Are There?, *https://www.westmarine.com/west-advisor/how-many-starlink-satellites-are-there.html*

[6] Project Kuiper, *https://en.wikipedia.org/wiki/Project_Kuiper*

[7] Eutelsat OneWeb, *https://en.wikipedia.org/wiki/Eutelsat_OneWeb#OneWeb_satellite_constellation*

[8] ESA confirms kick-start of IRIS² with European Commission and SpaceRISE, *https://connectivity.esa.int/news/esa-confirms-kickstart-iris%C2%B2-european-commission-and-spacerise*

[9] Guowang, *https://en.wikipedia.org/wiki/Guowang*

	China - Qianfan	Over 15,000 satellites planned[10]
MEO	EU / SpaceRISE / IRIS²	18 satellites in MEO (part of the IRIS² multi-orbit plan)[11]
	SES – O3b mPOWER / SES MEO services	Total about 13 MEO satellites (in the “global broadband MEO constellation”), in some sources, the final design has ~13 satellites
GEO	Intelsat	52 satellites (prior to full integration with SES)
	BeiDou Navigation System (China)	7 active satellites in the BeiDou-3 constellation as of late 2023
	SKY Perfect JSAT	17 active satellites

6.1.1 Low Earth Orbit (LEO)

As the current trend of large constellation deployment continues, a sustained use of IOS will aid in ensuring long-term sustainability of LEO operations. While regulations such as the five-year disposal rule have been introduced to reduce debris, in practice certain orbits will not be able to comply 100% with timely deorbiting without the assistance of servicing spacecraft. The increasing density of satellites in multiple shells will therefore create persistent demand for active debris removal, relocation, and last-mile transfer services. This implies that IOS in LEO will not be a one-time intervention but rather a continuous operational requirement integrated into sustainable constellation life cycles.

6.1.2 Medium Earth Orbit (MEO)

In MEO, dominated by navigation satellite constellations, the constraints of orbital altitude and mission criticality mean that direct compliance with accelerated deorbit timelines is often impractical. Satellites operating in these orbits are long-lived, high-value assets, and their replacement cadence is closely tied to industrial and strategic policies. Here, the role of IOS may be in orbital boosting, repositioning, and life-extension, ensuring continuity of service while avoiding costly premature replenishment. Much like in GEO, the economics strongly favour servicing: extending the operational lifespan of a GNSS satellite through refuelling or orbit adjustment can provide more value than immediate replacement, while also preserving spectrum and orbital slot allocations.

6.1.3 Geostationary Orbit (GSO)

In GSO, the cost and complexity of communication satellites could make repairing, refuelling, and extending life far more economically attractive than replacement. Continuous IOS capabilities are expected to become embedded in the GSO operational model, particularly as more administrations and operators demonstrate proximity operations and servicing missions. Commercially, this trend is already visible through life-extension missions, and it will intensify as second-generation servicing vehicles introduce multi-client capabilities. Given the high replacement cost of GSO assets, IOS is not only a sustainability measure but also a means of generating significant economic value, reducing capital expenditure for operators and ensuring resilience of global communication infrastructure.

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[10] Qianfan, *https://en.wikipedia.org/wiki/Qianfan*

[11] IRIS², *https://en.wikipedia.org/wiki/IRIS%C2%B2*

7 Assessment of Other Frequency Bands That Could Support IOS

7.1 Criteria for Band Selection

IOS missions make use of diverse radiocommunication links that differ substantially from conventional satellite operations. Its spectrum requirements are strongly dependent on operational phase and mission profile. The following attributes can be used to characterize IOS frequency usage:

- **Time-dependent communications –** Communications demand are not uniformly distributed across the mission timeline. Periods of limited activity, such as during servicer standby or in parking orbit, may alternate with periods of intensive usage during mission critical operations (e.g., RPO phases).
- **Priority of transmissions** – Criticality of links changes with mission activity. For example, during RPO phases, continuous and highly reliable links are required to exchange sensor and control data that ensure collision avoidance. By contrast, during station-keeping or standby phases, lower-priority TT&C links may be sufficient.
- **Duration of transmissions** – Communication may be continuous or intermittent depending on mission requirements. RPO phases may require short period of continuous links of extended duration from hours to days, whereas routine TT&C operations typically require shorter, periodic links throughout the mission.
- **Throughput** – Data rate requirements vary by mission phase. For example, high-throughput links may be required to transmit live video or sensor data during RPO phase, whereas phases limited to routine TT&C require low-throughput links.
- **Direction of transmission** – IOS missions utilize communication links to and from the ground stations (uplink/downlink) as well as space-to-space links such as proximity sensors.
- **Variability in orbit and spacecraft orientation** – IOS typically requires multiple changes in orbital altitude and spacecraft attitude during a single mission. Altitude ranges can span several hundreds of kilometers and servicer attitude requires full-sphere flexibility during six-degree-of-freedom operations. Furthermore, the precise timing of orbital and attitude adjustments cannot typically be predetermined, as rendezvous operations depend on dynamic client orbits and attitude rates, and must be responsive to evolving environmental conditions and customer demands.

These attributes make spectrum usage for IOS more complex than that of conventional satellite operations. Spectrum allocations accommodating IOS must therefore account not only for continuous, predictable links, but also short term, high-priority, high-throughput communications that occur during specific, mission-critical phases.

Considering the above, there are two major transmission elements for typical IOS spectrum usage which are to: 1) collect and transmit sensor data, and 2) perform TT&C operations. Each of these usages will likely have a different bandwidth requirement.

There are several requirements to consider when assessing frequency bands for IOS including:

- **Bandwidth** – Data volume, throughput and latency vary across mission phases. Routine TT&C requires relatively low bandwidth, whereas transmission of sensor data would require higher bandwidth in the order of tens MHz, depending on missions.
- **Propagation characteristics and weather resilience** – Atmospheric attenuation, rain fade and scintillation increase with frequency. Lower bands such as in 2 GHz or 8 GHz ranges provide higher resilience to weather effects and suitable for safety-critical control. Higher

bands such as 17-21 GHz support higher throughput requirements but suffer more from increased weather effects and design complexities such as higher mass and power requirement hardware.

- **Link availability** – Safety-critical functions require very high availability whereas routine TT&C can tolerate limited outages.
- **Power and antenna constraints** – Servicer spacecraft often face strict size and directivity limits, especially during proximity operations which require safe physical clearances and six-degrees-of-freedom movement. These constraints directly influence feasible antenna designs and operating frequency bands. Higher bands require larger antenna, higher power and overall mass of a servicer spacecraft.
- **Technology maturity and equipment availability** – Mature supply chain and flight-proven hardware for a certain band such as in 2 GHz or 8 GHz ranges can minimize procurement risk and integration complexity. By contrast, higher bands such as 17-21 GHz and optical systems rely on newer technologies with limited operational heritage which may affect program cost and schedule risk.
- **Ground infrastructure and compatibility** – As IOS entails safety-critical operations, reliance on established global ground networks, existing TT&C systems, and known regulatory constraints is critical. Certain frequency bands such as in 2 GHz or 8 GHz ranges benefit from established infrastructure whereas higher bands such as 17-21 GHz and optical systems may require new gateways and site diversity.
- **Orbital range flexibility** – The need for IOS missions to operate across a wide range of altitudes within a single mission may make it incompatible with existing spectrum filing strategies and orbital tolerances defined for conventional satellite services. The propagation conditions, coordination, interference prediction, and regulatory compliance must enable this flexibility.

7.2 Evaluation of bands that could support IOS

Preliminary assessment suggests that frequency bands in 8 GHz ranges appears to meet the criteria mentioned above and offers a balanced technical and practical solution for IOS communication needs. It provides the necessary performance for spaceflight safety during RPO, while also supporting moderate data rate requirements. This band benefits from favourable propagation characteristics and weather resilience, widespread ground infrastructure and a mature technology and equipment availability.

Higher bands and optical, may play an important role in the future to meet high-throughput demands. However, their current limitations in terms of propagation characteristics, technology maturity, pointing constraints, and ground infrastructure availability suggest that frequency range in 8 GHz presently represents the most favorable and robust near-term option for IOS communications.

Comprehensive technical and regulatory assessment of all potential bands should be undertaken in a subsequent ITU-R studies considering IOS technical characteristics, operational and regulatory requirements as well as sharing and compatibility with incumbent services. This report is intended to provide preliminary technical insights and operational experience that can guide future studies.