IOT4EO WORKSHOP 2

Executive Summary

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i. Introduction

The 2nd instalment of IoT4EO Workshops, a forward-looking assembly that convened on **2-3 December 2024** in hybrid format, with presence at ESA-ESTEC **and also on-line via Webex**, aimed to showcase results & feedback that were identified through *(1) ESA System Studies*, *(2) IoT4EO Surveys* and *(3) IoT4EO Service Definitions & Preliminary Specification* document for integrating Low Power Wide Area Network / Internet of Things (LPWAN/IoT) Technologies with Earth Observation (EO) satellites in Low Earth Orbit (LEO) for low-data-rate near-permanent connectivity. It encouraged the formation of partnerships, collaborations and multidisciplinary dialogue between Space Agencies, technology providers, and end-user communities to advance the IoT4EO Ecosystem.

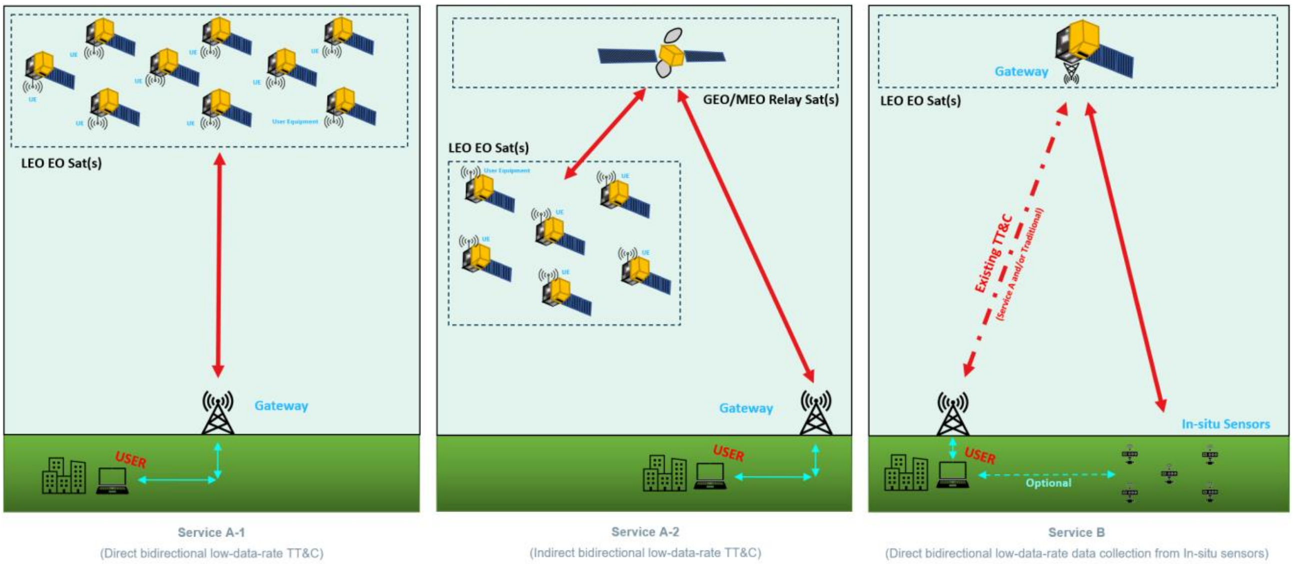

Figure 1 The proposed Low-data-rate connectivity service categorization

The workshop was split into four sessions, spanning three half days, which covered:

- **Session 1 IoT4EO Service Definition & Preliminary Specification.** This session explored the service definitions & preliminary specification identified in the ESA IoT4EO studies with ADS and OHB, incl. ESA Earth Observation (EO) use cases

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- **Session 2 Users & Requirements:** This session explored the Earth Observation (EO) use cases within the industrial and commercial landscape, incl. the perspective of current and potential end users of a low-data-rate near-permanent connectivity service
- **Session 3 Service Providers & Interoperability:** This session explored existing connectivity services and infrastructure including the perspective of existing and potential providers of a low-data-rate connectivity service.
- **Session 4 Breakout Session & General Discussion**: This session aimed to foster dialogue among various stakeholders involved in the provider-agnostic architecture to develop a roadmap, identify intervention points, and outline next steps.

A total of 105 registered attendees, with 30 on-site and 75 via Webex.

ii. Key takeaways

Session	Summary
Session 1: IoT4EO Service Definition & Preliminary Specification	Overall, the *IoT4EO Service Definition & Preliminary Specification* document offered a common centralised source and reference for all stakeholders to interrogate and offer feedback against. In this sense, the document was successful, with a diversity of stakeholders offering detailed feedback. It was emphasized that the document is open with the objective to allow all stakeholders to feel a sense of ownership and contribution. The goal is to engage in dialogue and consider the impacts on all stakeholders, ensuring they are represented. To this end, stakeholders are encouraged to actively participate in the document's development. **General Feedback** **Service Definition Document – Service B underrepresented**: • Underrepresentation of in-situ sensor specifications (service-B) → Not as trivial as the document make it out to be. Thus, it calls for more representation of Service-B stakeholders in future service specifications. **Service A and Actionable information** • Repeated discussion about distributing **actionable** or **insightful** information through Service A, not mainly for TT&C exchanges. • The use cases #2 (UC2) called "TM for EO satellite" and #9 (UC9 "Broadcast information") do not emphasize enough the idea of bringing to Earth actionable information (assuming some edge computing capability) can be distributed through low-rate LPWAN / IoT communication. **Interoperability** • There is a common need for creating scalable, plug-and-play type of solution. The more barriers we remove, the higher the anticipated adoption of the solution, addressing challenges like roaming and access to multiple networks. It's not only a timing-latency issue, but also a risk issue regarding continuity and availability of service provision.

Session	Summary
	• Existing Service A-2 Solutions: Viasat's L-Band GEO Network already in use by many EO users and with at least three equipment providers supporting the service. **Onboard Processing & Protocols**: • Interaction → Onboard processing requirements for EO use cases deemed very important to complement the value of the LPWAN communications. • Protocol specification → Important information → Greater needs to be considered deemed important, with calls for greater interoperability. • Clear recommendation to develop common Application Programming Interfaces (API) **Pre-requisite**: • SWaP (Size, Weight, and Power) → Very important characteristic, especially for small satellites, as LPWAN highlights that low power is an integral aspect. **IoT4EO Surveys**: • While the surveys were generally well-received, concerns were raised by all stakeholders, incl. ESA, about ensuring unbiased results given the **too limited number of responses** (about 10 for EO users, and 10 by Service providers) and skewed representation, particularly favouring stakeholders with a EO satellite provider profile. • To address this, it was recommended to conduct, in the coming months, a new set of surveys that feature more targeted questions. Overall, the importance of a provider-agnostic architecture was acknowledged for widespread adoption. One important concern is continuity of the service, which is less risky in the context of provide-agnostic services. **Specific Feedback** **IoT4EO ESA Studies (one with Airbus Defence Sys. (ADS) + one with OHB):** (presentations available at the Workshop site *Session 1*) • Performance → Link budgets confirm feasibility of low-data-rate connectivity (Serv. A & B definitions and architecture). The data rate achievable with Service A-2 (via ISL) can be higher than with Service A-1 due to the high directivity of the ISL antennas. • Freq. opportunities → AI 1.12 for 1-2 GHz, LoRa Alliance involvement (27 members), and NB-IoT challenges (negotiations with license owners and large spectrum overlap). • LoRa LR-FHSS could be an interesting alternative not studied yet, and result in an Increased capacity (100x) at the expense of lower data rates. • Technical Challenges mentioned → Min. Elevation Angles (MEA - (55° start for Serv. B), Scalability (network roaming), Limitations in NB-IoT Signalling & spectrum availability, variance of LoRa Protocols and provider dependency (e.g. SemTech).

Session	Summary
	• Space stakeholders currently **with very limited presence in LoRa Alliance**, but this **should change** if we want to influence or learn more details on for example roaming in Service A-1 • Future work → System studies for Serv. A-1 (e.g. roaming) & spectrum allocations for WRC27.
Session 2 **Users & Requirements**	Overall, the presentations from potential users were of high quality. Many referenced and used the *IoT4EO Service Definition & Preliminary Specification* document as a common centralized resource, using it to provide specific feedback, which further underscored its value. Users highlighted the importance of affordable, scalable, and federated connectivity for Earth Observation (EO), with specific requirements for low-latency (near-permanent) communication, on-board processing, and End-to-End from tasking to delivery of actionable information delivery within (e.g. 15) minutes. The under-representation of in-situ sensor specifications (service-B) was reinforced and is recommended to explore it further. It was made clear that collaboration across diverse stakeholders is essential to address these complex challenges effectively. **General Feedback** **Earth Observation Use Cases**: • Civil Security: Maritime security, environmental monitoring, humanitarian crises, and crime investigations highlighted. • In-situ validation networks → Essential for improving EO data reliability in remote areas • Connectivity ground-space assets needed within a few (e.g. 15) minutes between identification of the need and availability of actionable information by end-user • Currently a lot of efforts developing on-ground infrastructure (e.g. data hubs) for heterogenous systems, but not enough on affordable and federating connectivity for ground-space assets. **User Expectations**: • Mixed perspectives on latency; some users prioritize immediate insights, while others see it with lower urgency. • Scalability and affordability critical for adoption by some users. **Key Questions**: • How to combine both on-board processing and communication capabilities technologically and within in the development process of LPWAN/IoT. ○ Note: Users with on-board and edge processing seem to be willing to combine it with competitive communications like LPWAN/IoT to deliver "actionable" information "in-time" (within minutes) • How to bring all "stakeholders" together of the service-chain and to identify the specific tasks for each of them.

Session	Summary
	◦ Note: there is a big interest by the EO users to gain value by delivering "actionable" or "federating" information "in-time" though near-permanent connectivity. However, it is very complicated to make such connectivity operational because the system needs to be "scalable" and possibly in "provider-agnostic" and this requires the collaboration between many stakeholders with a different service profile in the overall service-chain. **Specific Feedback** (some presentations available in the Workshop site *Session 2*) **ESA // Civil Security from Space: Thibault Taillade (ESA EOP-S):** *(presentation shared only with IoT4EO Workshop participants)* • IoT potential for revisits, timely delivery, and integrated EO and IoT solutions. • SERENITY pilot project by ESA as part of the Civil Security from Space (CSS) Programme and Rapid and Resilience Crises Response (R3) accelerator mentioned, with a number of ground-to-ground Hub developments • There is a number of IoT availability studies and overreliance on isolated IoT or imagery, but currently without addressing ground-space connectivity. • The focus of the presentation was on applications that need Service A, but Service B is also very interesting. **NASA // Novel Observing Strategies (NOS): Louis Nguyen:** • Internet of Earth Things (IoET) with constellation of Sensors, Models, in-situ IoT sensors, etc. • NOS Testbed architecture Framework documentation and Open-source software • Multiple projects like Ground Station Observation Network (GSON), Decentralized-Distributed-Dynamic Sensor System (3D-CHESS), Dynamic Targeting, D-shield, Observing Earth's changing surface topography & Vegetation structure • These projects need a combination of real-time processing and a good connectivity space-ground, which in some cases can be achieved with high-speed Intersatellite Links (ISL) for high-volumes of data, but lower-data rate with hopefully more affordable IoT4EO service is also considered as a very good option • There is a need for both, Service A and Service B **Orotatech // Real-time Wildfire detections and IoT: Max Bereczky** *(presentation shared only with IoT4EO Workshop participants)* • Requirements for rapid data download (minutes). • Already using Service A-2 with Intersatellite Links (ISL) with Doppler-related constraints, and intending to initiate the use of Service A-1. • Key use case: wildfire monitoring. • The scalability should be for much more than the 500 satellites specified in the *IoT4EO.Serv.Def.Prelim. Spec*.

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<tr><th>Session</th><th>Summary</th></tr>
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Other recommendations: improve connectivity by x100 (rather than x10), service support is very important, provider-agnostic will be important to reduce long-term risk related to service-continuity (not just for short term availability)

Planetek // Edge cognitive distributed processing in LEO: Vito Fortunato:
(presentation shared only with IoT4EO Workshop participants)

Emphasis on low-latency data transfer and low-latency edge processing: need for system integration.
Recommendations: need to further detail taxonomy and standards for IoT4EO.
Partnering with another participant to the Workshop for the transceivers

Vision Space // ParleIoT – Say more with less data: Milenko Starcik

Focused on data compression (2-20x factor) for Serv. A-1 and Serv. B
Challenges: scalability, power constraints, and cost-effective IoT solutions, hence the need for data reduction.
Need to increase End-to-End system, including definition of ground protocols (e.g. AMPQ, MQTT) with relevant stakeholders

Eodyn // Ocean Sate Monitoring Systems (Service-B): Yann Guichoux:

Focused on sea-state monitoring via AIS and drifter sensors.
Cost of connectivity with LEO satellites is considered very high, and a provider-agnostic service would be highly beneficial
→ Big interest in Service-B

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<tr><td>Session 3

Service Providers & Interoperability</td><td>
General Feedback

Spectrum & Infrastructure Challenges:

Spectrum allocation remains a critical bottleneck.
Regulatory focus required to resolve disputes and define frequency usage.

Interoperability:

LoRaWAN and other open protocols emphasized for coexisting systems.
Avoiding proprietary lock-ins at the communication layer to ensure flexibility.
Need to define API's or service end points at IP layer. The IP layer seems to be an acceptable layer to build interoperable services upon.

Existing Services:

Need to focus on plug-and-play base stations to simplify adoption.

Specific Feedback
(some presentations available at the Workshop site Session 3)
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ESA // IoT4EO Services (A1, A2, B) in 5G & 3GPP: F. Zeppenfeldt (EOP-TIA):

Serv.A1: On-going activities, 5G NTN 800MHz Space <--> Ground (on-going co-financed ATRES); GSM-to-space study 15 years ago.
Serv. A2: On-going activities, new planned activities and collaboration opportunities with IRIS2 which has a Data Relay component and relies on 3GPP (5G) and potential market shifts by Starlink and Iridium also regarding 3GPP. In ARTES AT/5G SPL it is planned to have:

800 k€ - To fly an NB-IoT UE on a satellite, which is then served via GEO relay. Tender appearing before summer 2025.
2000 k€ - 5G NR NTN UE on a satellite using FR1 spectrum, similar as above to act as a data relay

Serv.B: On-going activities, both for on-board gateways as well as work on protocol stacks. Open for more co-financed projects.

3GPP NB-IoT NTN on-board developments ongoing.

NEOSAT [DE] // UCSS for EO Connectivity: Kai-Uwe Storek

Service A1 - Already a partner with Ororatech.
Roll out early 2025 with heritage from A2 service
Flexible frequency use; scalable to multiple-user capabilities.
Kbyte per overpass needed
Easy API needed

AddValue // Inter-Satellite Data Relay Service: Eyal Trachtman

Service A-2 with competitive SWaP for the transceiver and antenna
Solid operational service full duplex at 200 kb/s with IDRS (Inmarsat/VIASAT) in L-band with 20+ LEO satellites and 50+ IDRS terminals prepared for launch; scalable to thousands of terminals.
First operational customers in 2020
IP based, with a VPN service wherever in the world. Always on connectivity
Latency 0.5 to 1.5 seconds end-to-end

I/Q SPACECOM [DE] // Global on-demand bi-directional ISL: Thomas Kühne

Service A-2 for small satellites, with pay-as-you-go service
connection to IDRS (Inmarsat/VIASAT) in L-band
Competitive SWaP solutions with 4-128 kbps data rates.
Flying successfully in CubeSats since Aug.2024

TTP [UK] // LEGERA Inter-satellite relay terminal: Lewis Davies

Service A-2 for small satellites, up to 200 kb/s
connection to IDRS (Inmarsat/VIASAT) in L-band

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Session	Summary

	• some mid-size sats customers already using the LEGERA terminal
	• the IoT4EO challenge is to have spectrum and the trade-off between Link Budget/Data rate vs SWaP vs in-orbit antenna coverage
	
	SatelIoT [ES] // 3GPP NTN 5G NB-IoT standardized connectivity: Judit Bastida
	• For EO Service B
	• Store-and-forward IoT architecture with NB-IoT NTN protocols in S-Band.
	• 4 satellites in orbit since Aug-2024, aiming at 100 satellite constellation
	• Full compliance to 3GPP Rel.17 5G NTN NB-IoT
	
	APOGEO [IT] // Picosatellites for IoT serving EO constellations: Guido Parissenti *(presentation shared only with IoT4EO Workshop participants)*
	• Picosatellites (10x10x3 cm) with LoRa for IoT using the VHF band;
	• Partnering with Planetek. Expanding constellation with 96 satellites by 2027.
	• With a kind of
	  ○ Serv.A1 based on Apogeo's ground boosters
	  ○ Serv.A2 , where the LEO Apogeo picosatellites are the ISL
	  ○ Serv.B, already in place with Apogeo modem in ground sensors
	• Challenge is to have power to transmit. Receiving is OK
	
	Challenges and Considerations:
	• Proprietary methods dominate Serv.A2 and Serv.B;
	• Serv. A1 is nascent but opening up.
	• SWaP, antenna designs, and service scalability are recurring themes.

Session 4 **Survey result & Breakout Session** and **General Discussion**	Overall, the 'IoT4EO Provider-Agnostic System Architecture' diagram (see below) served as a centralized reference point for all stakeholders, enabling them to identify their roles and potential interfaces. It played a pivotal role in facilitating and structuring the breakout session discussions, fostering more focused and targeted exploration, feedback, and the identification for standardization intervention opportunities. **Survey Results** (two presentations are available at the Workshop site – end of *Session 2* for users, and in *Session 4* for providers) The survey results were presented and well received as an initial effort to gather input for scoping the "provider-agnostic" landscape while also establishing a direct communication channel for feedback. While the significant limitations due to too few answers and potential biases within the results were acknowledged, several key improvements were identified such as:

Session	Summary
	1. **Survey Segmentation** – Splitting the surveys into **Service A** and **Service B** to enhance precision and address the underrepresentation of **Service B** users. 2. **Survey Refinement** – Tailoring the surveys to be more specific in some areas. 3. **Use Case Expansion** – Broadening the scope beyond **1-to-1** interactions to include **1-to-many** connectivity scenarios. 4. **Scalability Considerations** – Systematically addressing scalability challenges, particularly in relation to managing many more than **500 satellites** **General Feedback** **Roadmap Development**: • Provider-agnostic architecture emphasized to foster scalability, interoperability, and also to de-risk partners stopping the service. • Need to focus on layers that enable scalability and interoperability while keeping the performance and without increasing costs or complexity. **Regulatory Actions**: • Recommendation for **keeping** semi-regular **meetings** of this group and webinars to address spectrum allocation and regulatory challenges. • Need to be involved in frameworks like 3GPP or LoRa Alliance to represent EO (connectivity to LEO sats) -specific needs. **Collaboration Needs**: • For Serv.B, open sharing of Gateway locations (e.g. orbital data) for enhanced coordination with in-situ sensors could be beneficial in particular for energy efficiency in battery-powered in-situ sensors. • dialogue among stakeholders to identify intervention points is a must given the organisational complexity in a provider-agnostic context. **Key Open Questions**: • How to ensure scalability while maintaining flexibility in protocols? • Definition of specific roles for service providers, users, and regulators in advancing the IoT4EO provider-agnostic ecosystem? **Specific Feedback** **Key Topics:** • There is a significant challenge with multi-owner networks. • API (App. Programming I/F) requirements: between IoT UE and spacecraft, Mission Control Center (MCC) and network providers connecting to IoT Gateways; also further clarity is needed for Serv.B. • Protocol and spectrum interdependencies: IP-layer prioritization, store-and-forward capabilities. • Integration of IoT and traditional telemetry, tracking, and control (TTC).

Session	Summary
	Recommendations: • Align on 3GPP and LoRaWAN standards; explore multi-standard compatible solutions for uplink/downlink. • Keep in mind SWaP and antenna constraints for interconnectivity. • Standardize prioritization for EO satellite tasks and develop broader use cases (e.g., autonomous sensor triggers). **Provider-Specific Feedback:** • Need for cost-efficient terminals, flexibility in waveform design, and scalable business models.

iv. Conclusion and Next Steps

The workshop demonstrated sustained interest in this topic. The high quality of the presentations further reinforced the importance of ongoing discussions and collaboration within the IoT4EO community.

- All presentations and initial survey results (subject to confidentiality) are split in three categories:
  - some made publicly available via the **IoT4EO Indico TimeTable (Detailed view)** website.
  - some shared exclusively with **IoT4EO Workshop participants**
  - some retained only by ESA as the organizing body, and can be requested case-by-case
- This document serves as the **Executive Summary** of **IoT4EO Workshop #2** and is accessible on the **IoT4EO Indico** website in the Overview page.

As suggested during the workshop, the Provider-Agnostic System Architecture has been updated to include the traditional TT&C link (highlighted in yellow), emphasizing that the proposed low-data-rate connectivity services are intended to complement, not replace, existing services.

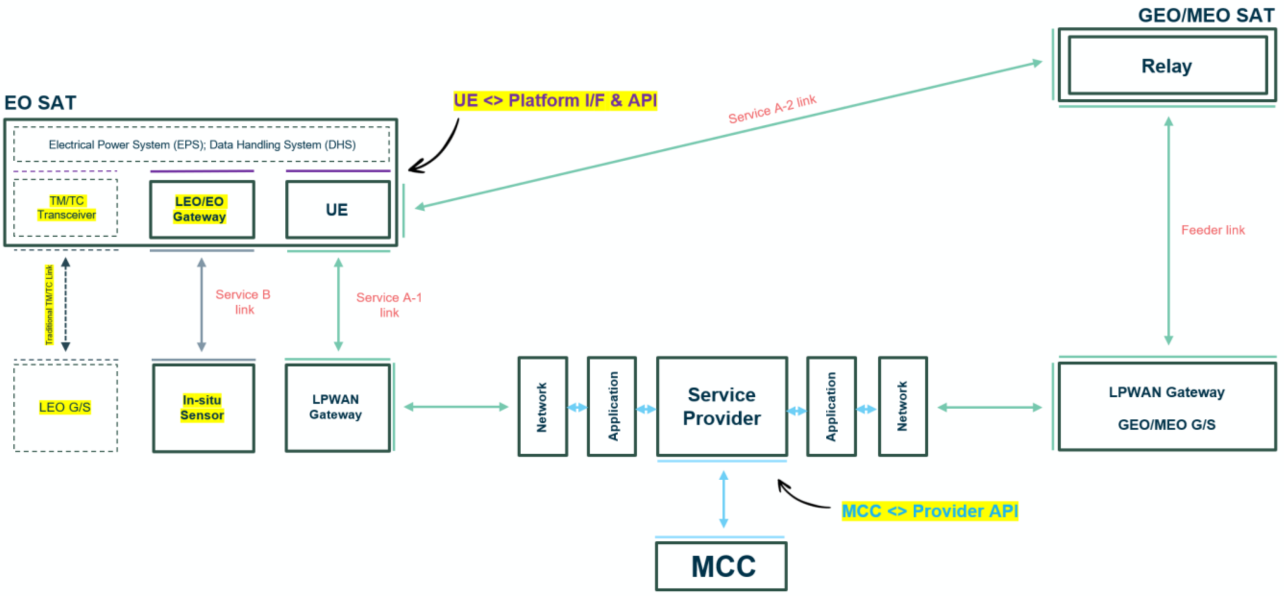

Figure 2 IoT4EO Provider-Agnostic System Architecture – Updated (in yellow) to include (1) Service B link, (2) The location of anticipated interfaces & APIs, and (3) Traditional TMTC Link to emphasize low-data-rate connectivity as a complementary role rather than replacement.

Based on the discussions during the workshop, the following key challenges and questions were identified as critical to developing and implementing a “provider-agnostic” system. Addressing these challenges will be essential in formulating a roadmap for future progress.

1. Improving the stakeholder representation in surveys and inputs?
2. Mechanisms required to enable affordable and scalable IoT4EO solutions?
3. Regulatory frameworks to better support spectrum allocation and management?
4. How to effectively address existing gaps in EO satellite tasking and data protocols?
5. Can current statistical methods for user engagement and insights delivery be improved?
6. Address the underrepresentation of Service B in the IoT4EO Service Def. & Prelim Spec.
7. Defining a service ontology to identify interfaces (e.g., APIs, Physical I/Fs etc…)?

AI	Topic	Action Item (Recommended)
AI-1	Frequency, Regulatory & Policy Roadmap	Organize a webinar (Q2/Q3 2025) on regulatory topics, alliances, and studies to support new frequencies to be prepare for a potential filing for WRC27 AI.
AI-2	IoT4EO Use Cases & Serv. B Underrepresentation	Broaden applications for civil security and autonomous EO operations, ensuring better representation of Service B and advancing near-real-time in-situ calibration & validation
AI-3	Technical Advancements & Collaboration	Address IoT energy efficiency, optimize data prioritization, and improve interoperability while fostering collaboration through new alliances and targeted studies
AI-4	Technical Demonstration of new services	Develop and perform an experiment with Serv. A1 and validate its technical feasibility through targeted system & technology studies
AI-5	Identification of interface specifications & APIs	Identify and define interface specifications, ensuring a clear API structure to demonstrate and supplement the “provider-agnostic” objective.
AI-6	IoT4EO Surveys Results & Preliminary Specification	Refine and update the IoT4EO-SERV-REQ-2024-09-196 document by incorporating feedback provided during the workshop. This includes survey segmentation to differentiate between Service A and Service B, addressing underrepresentation of Service B users, and survey refinement to ensure specificity and reliability of results.

Thank you all for your contributions,

AND DO NOT HESITATE TO PROVIDE US ADDITIONAL FEEDBACK, IF ANY.