EXECUTIVE SUMMARY REPORT

FIRST PHASE OF ESA SSI

AUTHOR(s):	Project Team	GMV	
APPROVAL:	**NAME**	**COMPANY**	**SIGNATURE**
Technical Responsible:	Jeremy Pierce Mayer	GMV	
PA Manager	Jeremy Pierce Mayer	GMV	
Project Manager	Jeremy Pierce Mayer	GMV	

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

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1. PROJECT DESCRIPTION

1.1. CONSORTIUM

The PPA-SSI activity was started in May 2024 and completed in December of the same year. The effort performed within PPA-SSI activity was divided into three primary categories, each of which was managed by a single consortium partner. These categories were:

- Technical
- Strategic
- Financial

This division of labor allowed each consortium member to focus on those activities to which they were well suited and brought unique skills. The division of these skills can be seen in Table 1-1.

Table 1-1 Consortium Structure

Consortium Member	Role
GMV GmbH (GMV)	▪ Project Management Lead ▪ Systems Engineering Lead ▪ Protocol Engineering
Novaspace	▪ Ecosystem Analysis ▪ Strategic Analysis ▪ Roadmap
D3TN	▪ Protocol Evaluation ▪ System Engineering ▪ Governance

1.2. SSI OVERVIEW AND CHALLENGES

The Solar System Internet (SSI) aims to provide a network-centric communication system between all classes of space assets and the ground. Additionally, for space assets, the SSI aims to provide Position, Navigation, and Timing (PNT) services for assets located beyond earth orbit. In parallel, the SSI will enable the next generation of space-to-ground links (e.g. Ka-band, optical). The SSI will impact all phases of future missions, from initial mission design to operations. Therefore, the technologies used within the SSI must be supported by robust laboratory testing facilities. Key communication use cases include the transfer of vast amounts of data from remote sensing satellites to Earth, providing critical information for weather forecasting, environmental monitoring, and disaster management.

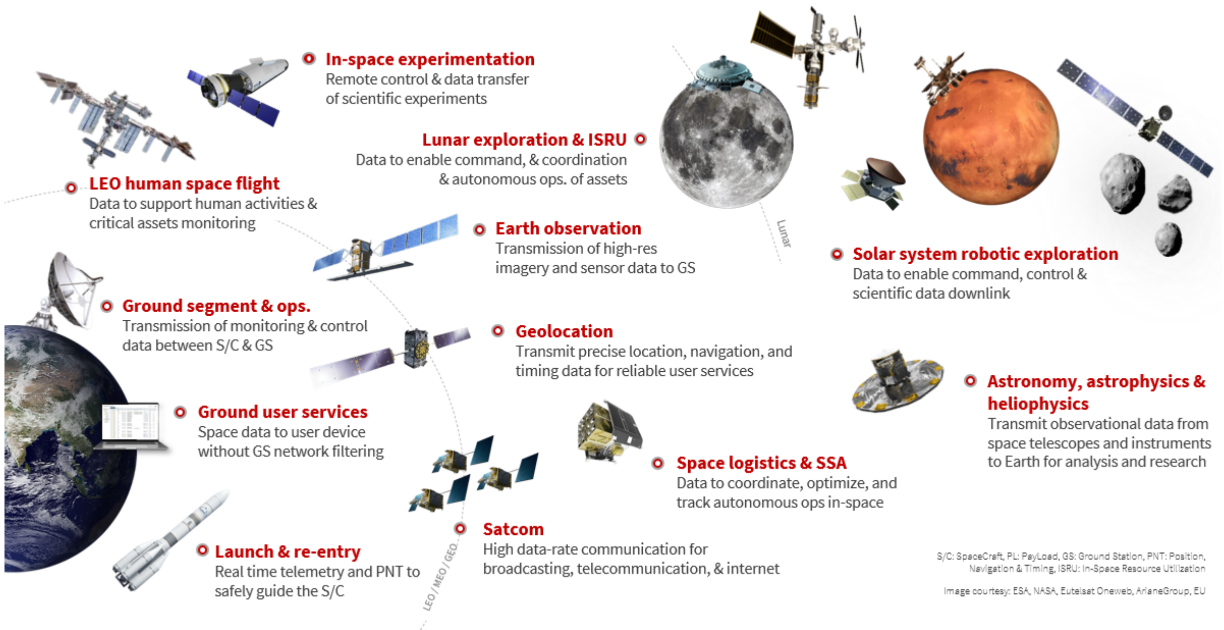

Figure 1-1: Overview of the role of communication functionalities within space applications

Communication has a specific enabling role in each domain of the space economy, meeting varying needs in terms of data rate, latency, resilience, reliability, coverage, link availability, range, and many other aspects per each different space application, as depicted in Figure 1-1. Effective communication ensures that space missions, whether for Earth observation, deep space exploration, or satellite-based services, can smoothly achieve the respective targets.

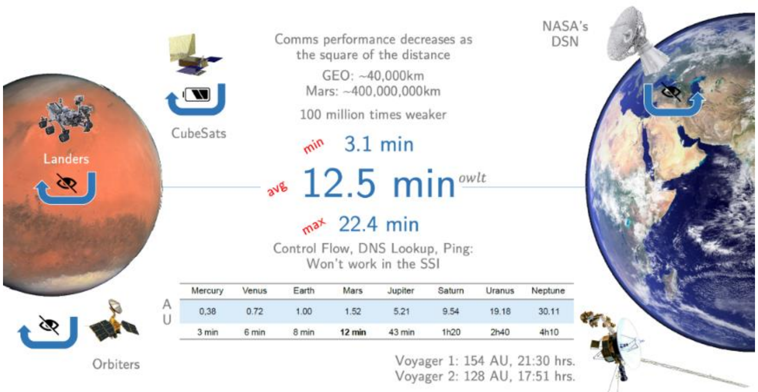

Figure 1-2 Communication Challenges in SSI

Figure 1-2 provides a stark visualization of the communication challenges within the context of the SSI. It underscores that as we extend our reach into space, the traditional internet protocols that rely on relatively low-latency connections become inapplicable. With the communication signal strength diminishing as the square of the distance, data from Mars becomes 100 million times weaker by the time it reaches Earth, compared to a geostationary orbit at approximately 40,000 km. This is exemplified by the varying communication delays, ranging from 3.1 minutes at the minimum to a substantial 22.4 minutes at the maximum, with an average one-way light time to Mars of 12.5 minutes. As a result, traditional communication methods cannot function effectively over such vast distances and with such delayed transmission times. This necessitates the development of new technologies and protocols for the SSI, where information must traverse millions of kilometres across the solar system.

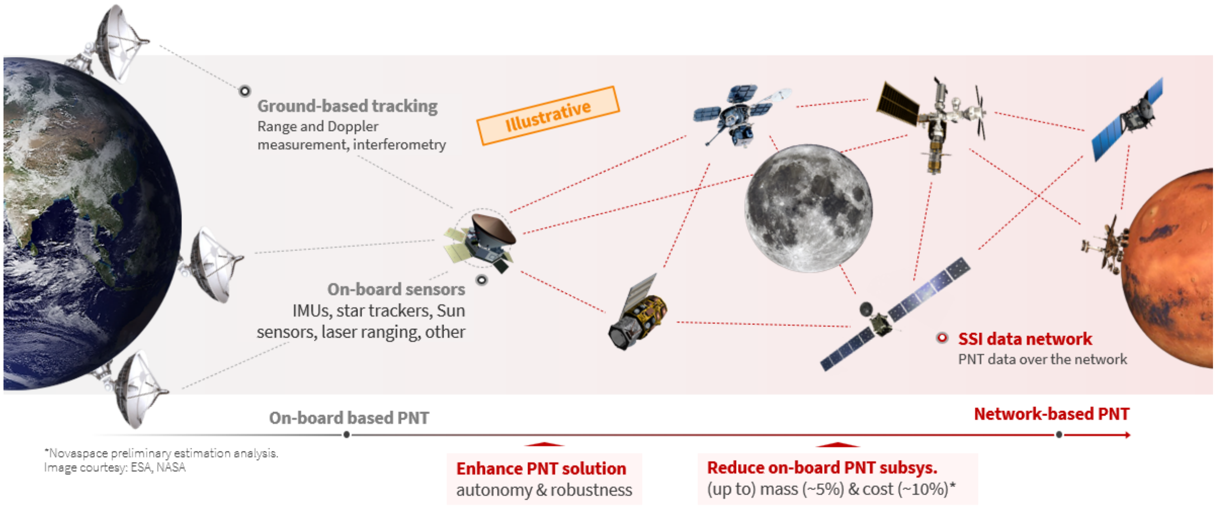

Figure 1-3: Beyond-Earth PNT Technologies

Positioning, Navigation, and Timing (PNT) technologies are critical for the successful implementation of these networks. PNT systems provide the essential data needed for accurate positioning, reliable navigation, and precise timing, which are fundamental for the coordination and operation of space missions. These technologies include Global Navigation Satellite Systems (GNSS), such as GPS, Galileo, and others, which offer satellite-based positioning and timing services. Additionally, advancements in optical communication and space internetworking are paving the way for more robust and interoperable PNT solutions.

With the introduction of the SSI, a spacecraft connected to the data network would receive, on top of mission-specific data packages, also PNT information relative to the other nodes. Figure 1-3 gives an illustrative summary of how the SSI might impact the architecture of in-space navigation functionalities. The PNT information provided by the SSI network can be used on top of other sensor data for enhancing the autonomy & robustness of the navigation solution. In the longer term, when the spacecraft is connected to a mature SSI network, PNT information provided by a wide array of nodes to the spacecraft might progressively replace onboard sensors. Removal of onboard PNT hardware might enable mass & cost savings of up to 5% and 10% respectively, depending on the specific mission & system requirements. While this is particularly the case for spacecraft beyond MEO that cannot rely on GPS/GNSS capabilities, spacecraft below MEO would still benefit from the SSI, which would provide an additional source of PNT data independent of dedicated infrastructure, thus increasing the resilience of the respective navigation capabilities.

2. ROLLOUT

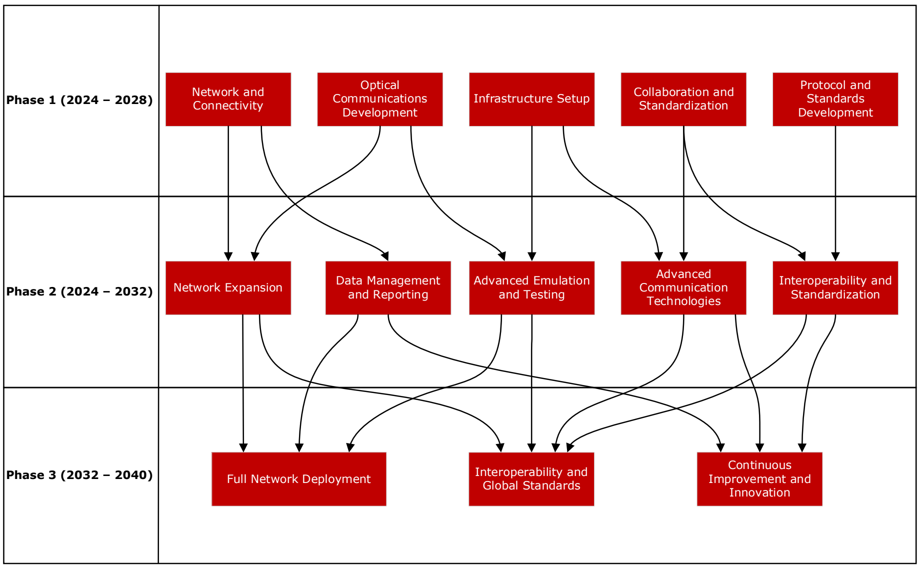

Figure 2-1 Rollout Plan

By analysing the technical and strategic roadmaps outlined during this activity, it is possible to devise a rollout roadmap as shown in Figure 2-1. This roadmap is based on the use-cases, mission requirements, and laboratory facilities. Functionally, this roadmap is based upon the expansion of existing laboratory and test facilities (along with lower-TRL missions). This facilitates the parallelization of development, and defines the steps necessary to support and encompass the upgrade of the current existing infrastructure towards the development of SSI, utilising the capabilities of the proposed SSI laboratory and aligning with the strategic orientations of the Moonlight, LunaNet and Mars exploration programmes.

2.1. STANDARDISATION AND GOVERNANCE

To create an SSI architecture that allows for the collaborative participation of different entities, such as space agencies and actors from the private sector, the adherence to well-defined standards is critical. The standards development process therefore ought to incorporate the expertise and perspectives of various stakeholders, with the aim of advancing the interests of all parties engaged in the SSI. With the key standards bodies for the SSI established in the previous section, the focus now shifts to examining the process by which SSI-related standards may be developed.

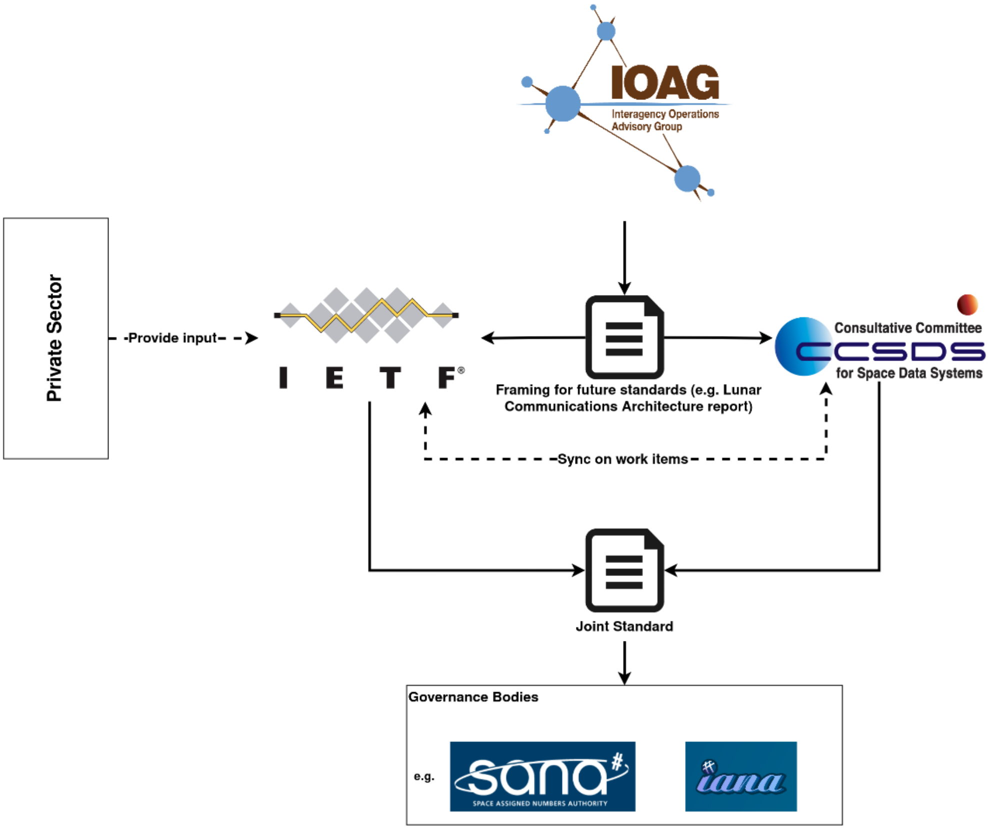

Figure: Potential Standardisation Process for the SSI

One way this process could work is shown in the above figure. As mentioned in the overview of standards bodies, the IOAG is the main entity responsible for identifying and analysing challenges affecting interoperability between space agencies. Therefore, the IOAG reports can be used as indicators of areas for which new standards are needed. In this way, the IOAG provides the framing for these new standards, which can then be developed by the other standards bodies. A critical factor in the standards development process is ensuring the commonality and interoperability of the SSI, as there are differences between industry-driven standards (such as those developed by the IETF) and more formal standards developed by the CCSDS/ISO. For example, for standards related to Delay- and Disruption-tolerant Networking, the CCSDS incorporates IETF standards into its own through so-called "protocol profiles". This is done to ensure that the protocols are appropriately tune for the space environment while maintaining interoperability with the general community. In terms of standards for the SSI, it would therefore be beneficial to strengthen the connections between the IETF and the CCSDS so that joint standards can be developed

The SSI is supposed to serve diverse entities from space agencies to actors from the private sector. This makes governing the SSI a complex issue, as it is unlikely that a single organisation will be able to oversee it. Both the IOAG and the Internet Society's Interplanetary Networking Special Interest Group (IPNSIG) therefore recommend a multi-stakeholder governance structure similar to that of the modern Internet. The organisations included in this governance structure, as well as important governance elements, are explained in more detail below.

The following figure[1] illustrates a possible view of the relations and dependencies between these organisations, space agencies and companies from the private sector, and the standards bodies presented in the previous section.

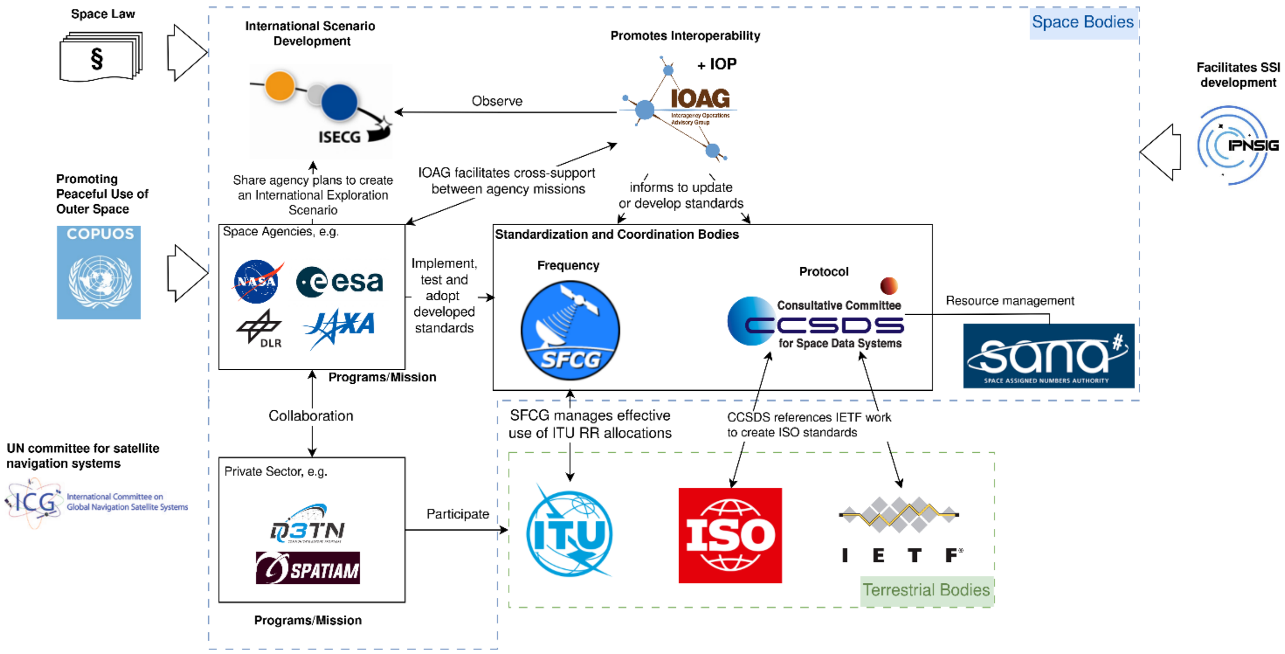

Figure: Relation among relevant organisations, agencies and companies in the SSI context

With the Solar System Internet Architecture and Governance report[2], the IPNSIG has created a comprehensive document highlighting key considerations pertaining to Solar System Internet Governance. In the report it is explained that - much like the Internet - the SSI will depend on standardised technical identifiers and interface protocols. The report further identifies several governance elements primarily related to infrastructure governance. These conditions must be carefully considered for the future deployment of the SSI.

[1] based on Figure 5 in the IPNSIG SSI Architecture and Governance report

[2] https://drive.google.com/file/d/1anMcVEqXjNtk5gdo_qce28SowusXKkfi/view

3. CONCLUSION

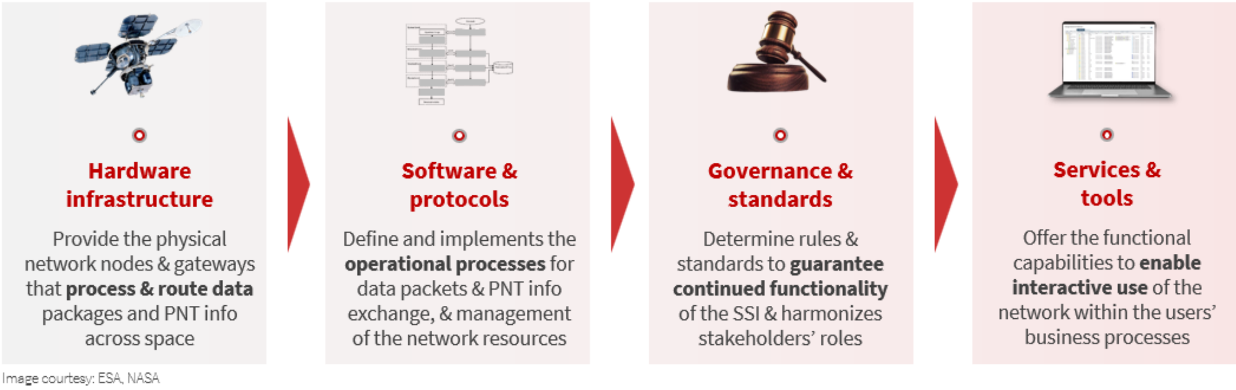

Figure 3-1: Overview of the SSI value chain

The SSI will provide resilient & scalable communication and PNT capabilities across orbital & planetary nodes by leveraging DTN based technology for implementing the packet routing store-and-forward mechanism. The SSI has the potential to increase link availability & end-to-end transmission latency by efficient management of resources for long-range space communication, while also enhancing PNT solution robustness & autonomy. To provide this value, the key components are the hardware infrastructure, including ground stations, spacecraft and operational assets, protocols & standards, such as the DTN and other relevant software implementations, governance & regulations issued & controlled by regulators, and finally services & tools that represent the interface of the SSI infrastructure with its diverse users.

This activity has aimed to consider all aspects of the SSI rollout, focusing on creating a scalable and interoperable network to support future exploration missions. Through a phased development strategy, the SSI addresses key infrastructure needs, expands capabilities, and targets full operational deployment of network-centric communication, beyond-earth PNT, supported by higher-rate communicate protocols. By utilizing novel technologies and governance/deployment models, the SSI will enhance mission safety, efficiency, and scientific discovery. Continued innovation, collaboration, and standardization will be essential to unlocking its full potential and ensuring its long-term success.