

LunaNet Governance: Organizing and Planning for LunaNet Operations

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Abstract

LunaNet has been conceived as the lunar Internet and more, providing services for communications, networking, position, navigation, and timing (CPNT) for spacecraft and users in transit to and from the Moon, in orbit around the moon, in transit to and from the surface, and on the surface. It is envisioned to unify and integrate, for cislunar users, the services that are presently provided separately in the Earth terrestrial environment by space communications satellites, Global Navigation Satellite Systems (GNSS), ground tracking networks, and the Internet. LunaNet is planned to be an open, international architecture with contributions from multiple organizations including international civil space agencies, commercial service providers, academic institutions, and other organizations. Using a combination of conventional and emerging technologies, LunaNet will create a lunar-centric network-of-networks that inherits some features of the terrestrial Internet but has unique characteristics that will drive substantially different operations. Government acquisition efforts have already begun to procure commercial lunar communications and navigation services. A multi-stakeholder approach to developing the community-wide concepts of operation has been initiated by the Interagency Operations Advisory Group (IOAG), which is formed of international government space agencies, that includes other international organizations such as the Internet Society, Internet Engineering Task Force, International Committee on GNSS, and Space Frequency Coordination Group as well as industry and academic participants. Products of the Committee to Study LunaNet Governance (CSLG) will include: the recommendation and definition of an initial international organizational governance structure; associated roles, responsibilities, and processes; and recommended steps to implement the governance approach. This paper will describe the plan for developing these concepts and coordinating them among the participating organizations.

Keywords: communications, networking, navigation, governance

Acronyms/Abbreviations

ASA	Australian Space Agency
ASI	Agenzia Spaziale Italiana
BP	Bundle Protocol
CCSDS	Consultative Committee on Space Data Systems
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CPNT	Communications, Position, Navigation, and Timing
CSA	Canadian Space Agency
CSLG	Committee to Study LunaNet Governance
DLR	Deutsches Zentrum für Luft und Raumfahrt
DTN	Delay/Disruption Tolerant Networking
ESA	European Space Agency
EVA	Extra-Vehicular Activity
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System

ICG	International Committee on GNSS
IETF	Internet Engineering Task Force
IOAG	Interagency Operations Advisory Group
IPNSIG	Internet Society's Interplanetary Network Special Interest Group
ISECG	International Space Exploration Coordination Group
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Organization
NASA	National Aeronautics and Space Administration
NavIC	Navigation with Indian Constellation
PNT	Position, Navigation, and Timing
QZSS	Quasi-Zenith Satellite System
RFSA	Russian Federal Space Agency
SANSA	South African National Space Agency
SFCG	Space Frequency Coordination Group
SSI	Solar System Internetwork
UAESA	United Arab Emirates Space Agency
UKSA	United Kingdom Space Agency
WSIS	World Summit on the Information Society

1. Introduction

1.1 LunaNet Overview

Multiple national space agencies are undertaking major new efforts to expand their exploration and scientific understanding of the Moon encompassing one or more orbiting space stations, a lunar surface base camp, human sorties to a variety of surface locations, scientific landers for the lunar far-side, and distributed sensor networks. A Base Camp and other systems expected to be deployed to a location near the lunar south pole will have periodic line of sight to Earth. Far-side landers and rovers will have no line of sight to Earth. This limits or prevents direct communication with Earth. Therefore, a lunar communication network is needed to transmit data between terrestrial networks on Earth and systems in lunar orbits and on the lunar surface.

Locations like the Base Camp will require many landings and launches to establish and sustain it as well as to support exploration and science missions. Landings, launches, and location tracking of mobile surface assets require highly accurate Position, Navigation, and Timing (PNT) service like the capabilities provided by terrestrial GNSS. Similarly, science missions, such as radio astronomy facilities on the lunar far-side will need precise location and timing as metadata associated with the sensor data. Consequently, the Moon needs a global Lunar Navigation Satellite Service like GNSS but with availability anywhere on and around the Moon. This limits the use of terrestrial GNSS which can only be used on the near-side.

The architecture and systems being developing by various countries to address these needs is called *LunaNet*, the Lunar Internet. Fig. 1 provides an overview of LunaNet's architecture. Rather than being defined as a traditional space/ground set of point-to-point links, LunaNet will provide routed service from any source node to any destination node, including lunar surface, cislunar space, Earth orbit, and Earth ground stations. This concept of multi-path, multi-hop, packetized/bundled data communications will be achieved using standardized networking protocols including Internet Protocol (IP) and Delay/Disruption Tolerant Networking (DTN) Bundle Protocol (BP) using surface and orbiting communication relays. LunaNet will consist of a network-of-networks contributed by a combination of cooperating national space agencies and commercial providers. LunaNet will also include CPNT services such as the Global Positioning System/Galileo-like navigation broadcast as well as search and rescue services. LunaNet is designed to be implemented and deployed incrementally, starting with a single satellite, and growing over time as demand dictates. The evolution of LunaNet will be much more controlled than the evolution of the terrestrial Internet but is intended to become part of the sustainable cislunar architecture.

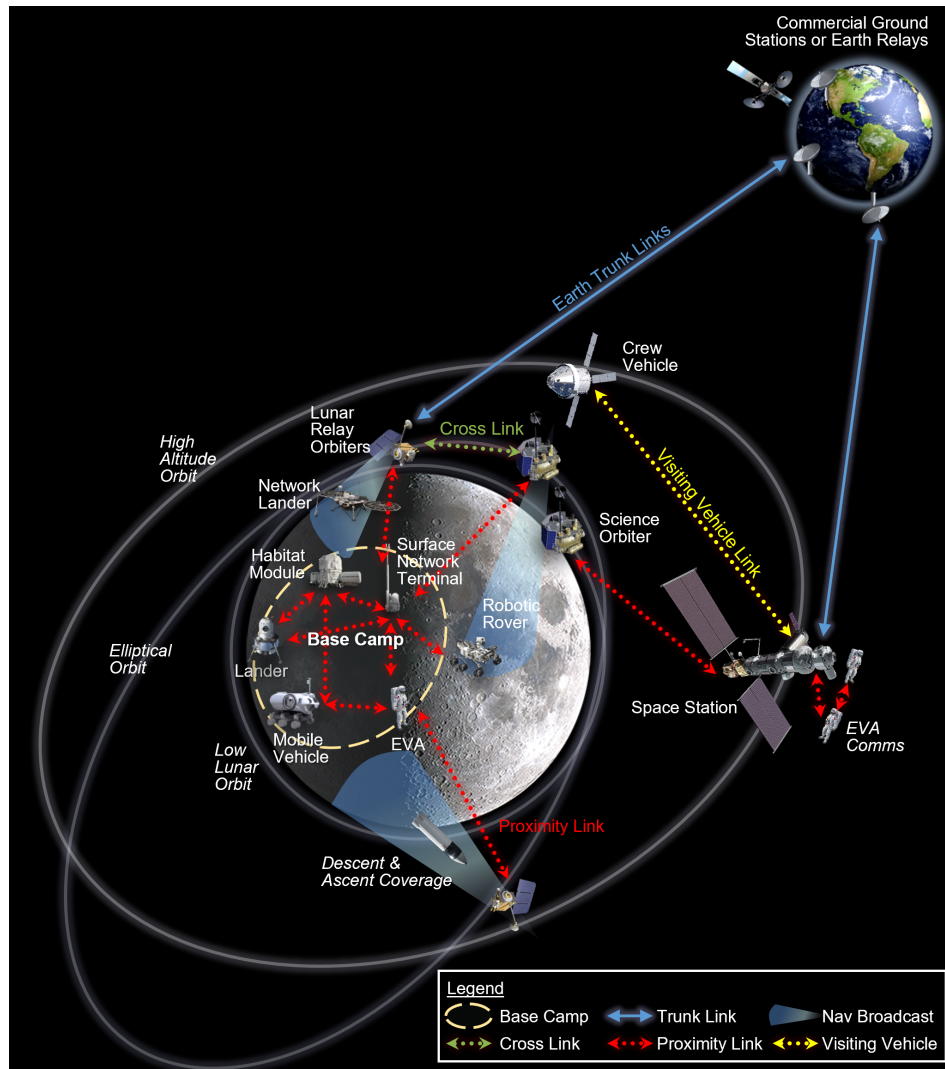


Fig. 1. LunaNet Architecture

1.2 Interagency Operations Advisory Group (IOAG) Background

The IOAG provides a forum for identifying common needs across multiple agencies related to mission operations, space communications, and navigation interoperability. The IOAG undertakes activities related to its goal of achieving and sustaining interoperability among member space agencies. [1] Member agencies establishing cooperative agreements for cross-support of missions include Agenzia Spaziale Italiana (ASI), Canadian Space Agency (CSA), Centre National d'Etudes Spatiales (CNES), Deutsches Zentrum für Luft- und Raumfahrt (DLR), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), National Aeronautics and Space Administration (NASA), and United Kingdom Space Agency (UKSA). Observing agencies that benefit from interoperability with agencies capable of providing cross-support include the Australian Space Agency (ASA), China National Space Administration (CNSA), Korea Aerospace Research Organization (KARI), Russian Federal Space Agency (RFSA), South African National Space Agency (SANSa), and United Arab Emirates Space Agency (UAESA).

Since many of its members plan to participate in or use LunaNet, in 2022 the IOAG approved establishment of a Committee to Study LunaNet Governance (CSLG), hereafter referred to as the Committee. The initial working definition of LunaNet governance is *the development and application by governments, the private sector and civil society, in their respective roles, of shared principles, norms, rules, decision-making procedures, and organizations that shape the evolution and use of LunaNet in the context of the relevant international legal framework*. [2] Civil society includes academia and non-governmental organizations like the International Telecommunication Union

(ITU) for spectrum management. The intent is that the recommended system of Governance will ensure accountability, transparency, responsiveness, rule of law, stability, equity and inclusiveness, empowerment, secure access, and participation by all stakeholders.

Many questions exist about how LunaNet should operate and be sustained in a dynamic and complex environment of rapidly evolving lunar capabilities and multiple national and commercial organizations with limited international legal and regulatory basis. The purpose of this paper is to describe the plans to perform a study that will recommend an approach for organizing and operating LunaNet. The IOAG invited other international stakeholders to participate such as the Internet Society, Internet Engineering Task Force (IETF), United Nations International Committee on GNSS (ICG), and the Space Frequency Coordination Group (SFCG). The plan includes growth to include industry and academic participants.

1.3 Vision

LunaNet is envisioned as a publicly available (open) architecture to provide CPNT services to cislunar users with international contributions from governmental, commercial, and other stakeholders that, consequently, requires international coordination and collaboration for operation and planning. The CSLG will recommend a multi-stakeholder organizational governance structure, approach, and functions, with their respective interface organizations, to develop guidelines, policies, and practices to help fulfil LunaNet's operational responsibilities. The Committee will study alternatives and produce preliminary LunaNet governance deliverables recommending how to achieve a comprehensive integration of the government, commercial, academic, and technical community, defining their respective roles in the development, application, and implementation of LunaNet governance.

The governance guidelines will provide a structure within which the multiple stakeholders and the implementing facilitating organization can effectively pursue LunaNet's mission. These guidelines are intended to serve as a flexible framework within which the recommended structure can carry out its activities to resolve issues and reach consensus on LunaNet decisions. The guidelines are subject to review by the Committee which may revise the Committee's organization, products, and processes as needed.

1.4 Objectives

In accordance with the Guiding Principles defined below, the Committee will produce a report recommending the multi-stakeholder organizational governance structure and related processes to achieve and maintain interoperability among stakeholders and facilitate the secure and efficient operational delivery of LunaNet services by LunaNet providers to LunaNet users. The Committee will divide into teams and hold regular meetings following a multi-phase plan to research relevant precedents, define and evaluate options, formulate recommendations, and document results, while promoting the full active participation of Committee members and considering all stakeholders.

The specific objectives are:

- 1) Define and recommend a LunaNet governance structure and approach, through which the coordination of architectural aspects such as space internetworking, PNT services, physical layer links (spectrum), security, protocols, and standards can be addressed.
 - a. Use and describe the national, international, and regional (if applicable) management process and coordination considering daily operations, incremental short-term evolution, and long-term planning.
 - b. Ensure that governance activities can be carried out by multiple stakeholders to resolve issues and reach consensus on LunaNet recommendations and decisions, employing them accordingly within their government, business, and academic organizations and in different regions while adhering to international treaties, conventions, and regulations.
 - c. Address the governance structure and approach to be able to develop a future platform where the different organizational bodies that will collectively govern the LunaNet will publish all their documents and work carried out, such as decisions, recommendations, reports, studies, etc.
 - d. Address the potential framework for international treaties and agreements, and national laws and regulations consistent with the larger framework of other inter-governmental and private sector involvement, including legal governance aspects such as private property rights, trans-border data rights, ownership, dispute resolution process, and venues for legal processes.
 - e. Ensure that governance can be extended from LunaNet to other planetary networks across the Solar System.
- 2) Define and recommend organizations that should participate in establishing the governance of LunaNet.
 - a. Identify their relationships either based on their CPNT functions or services, and any new organizations that should be established.

- b. Consider current international and national multi-stakeholder organizations and entities and build on their current roles in developing the governance structure. Examples: IOAG, SFCG, IETF, CCSDS, ICG, etc.
 - c. Consider resources required and cost estimates for the organization options. If the Committee recommends modifying the scope of existing organizations or establishment of a new organization that does not currently exist, the Committee should address how to provide resources and potential funding mechanisms for that proposed organization and/or new element(s).
- 3) Address the relationship and describe the differences between LunaNet and the Internet and determine how much Internet governance to adopt. Similarly, address the relationship and describe the differences between GNSS and LunaNet's cislunar PNT and determine the extent of GNSS governance to adopt.
- a. LunaNet will consider the Internet in terms of its architecture because of the similarity in architecture and services, and therefore lessons learned from Internet governance should also be leveraged to achieve governance of LunaNet.
 - b. LunaNet will consider the governance of various GNSS such as GPS, Galileo, GLONASS, BeiDou, QZSS, and NavIC that have separate national governance approaches in formulating a unified cislunar PNT governance approach.
- 4) Define and recommend steps to implement the approved organizational governance structure for LunaNet.
- a. Promote the adoption of the IOAG-recommended LunaNet approach.
 - b. Establish steps to transition the operational LunaNet governance.

Other specific objectives may be added as they are identified and coordinated with Committee members.

2. Guiding Principles

The following is an initial set of draft architectural and process principles that the Committee has agreed upon to guide their decisions related to the governance of LunaNet.

1. **Open Architecture:** Open (publicly available) architecture is a LunaNet design principle for the network to enable an environment with voluntary collaboration to share innovative and sustainable ideas, designs, and plans, and to address specific challenges from concept through implementation and operations. LunaNet governance must recognize the technical management principles for efficient network operation and preserve the end-to-end nature of the network. LunaNet's governance arrangements should avoid creating unnecessary burdens that could affect the potential for innovation with respect to technologies and services.
2. **Interoperability via Open International Standards:** LunaNet governance should promote, use, and adopt open international standards to the greatest extent possible to define the architecture and govern the communication, networking, and navigation functions of the LunaNet architecture, to allow for interoperable, resilient, secure, and interconnected networks.
3. **Scalability and Dynamic Connectivity:** LunaNet governance should preserve the architectural principle of scaling from a network with a single service provider node supporting a small number of users to an unbounded network-of-networks capable of supporting an ever-increasing number of users. Due to the orbits of the Earth, Moon, and satellites as well as the motion of surface systems, LunaNet also will have a constantly changing network topology that forms and reforms every time a node disconnects or reconnects.
4. **Security and Resilience of the LunaNet:** Operational security and resilience are key objectives in LunaNet's architecture. To preserve the integrity of the LunaNet infrastructure, as well as users' trust in LunaNet, governance structures and principles should be developed that assess and mitigate threats and vulnerabilities while creating a robust architecture that operates through and recovers from incidents.
5. **Consensus-based Decision-Making:** LunaNet policymaking, management processes and coordination should be achieved through broad representation of the LunaNet community, appropriate to its mission, and informed by practical experience and the individual and collective expertise of a range of stakeholders. Decisions should be reached through accountable processes that are based on consensus (multi-stakeholder model), where interested stakeholders can directly participate in the work and have access to its results.
6. **Open, inclusive, and transparent peer participation:** The development and implementation of LunaNet governance should transpire in an open, transparent, and accountable manner. The full participation of governments, the private sector, academia, and the technical community as peers, considering their specific roles and responsibilities should ensure that outcomes are effective and accepted. The development of LunaNet governance policies and arrangements must allow and promote harmonization, equitable access, and efficient use of LunaNet among stakeholders.

7. **Extensibility across the Solar System:** LunaNet will be architected and implemented to be a much more advanced network with integrated functionality, in contrast to the much simpler planetary networks that have been used in the past. The LunaNet architecture should be extensible to Mars and other instances in the Solar System, eventually forming the first planetary network of the Solar System Internet (SSI). [3]
8. **Availability of Services for all Lunar Users:** LunaNet services are intended to be made available for all users in the lunar region – in transit to and from the Moon, in orbit around the Moon, in transit between orbit and surface, and on the surface. To the greatest extent possible, services should have the same provider/user interface and service characteristics regardless of user location. The fully developed architecture should be able to expand coverage and capacity to meet user demand anywhere within the lunar region.
9. **Applicability of International Regulations:** Governance will be developed in accordance with applicable treaties such as the Outer Space Treaty and international regulations such as the ITU Radio Regulations while identifying possible changes to the international legal framework needed to govern LunaNet.

3. Committee Membership

The initial members of the Committee are the participating IOAG members and observers. The Committee will consult with organizations that have established liaisons with the IOAG, including:

- a. The Space Frequency Coordination Group (SFCG) provides international coordination and analysis of the spectrum and acts as an intermediary to the ITU which formally approves Radio Regulations.
- b. The Consultative Committee on Space Data Systems (CCSDS) develops international standards for space communication, networking, and PNT that have been adopted by hundreds of space missions.
- c. The International Committee on Global Navigation Satellite Systems (ICG) is a United Nations forum for coordination and interoperability among GNSS.
- d. The International Space Exploration Coordination Group (ISECG) integrates human exploration programs resulting in the Global Exploration Roadmap that describes the evolution of lunar and Mars systems.

The Committee may also consult with non-governmental institutions and organizations such as:

- a. Industry Consortia and Members
- b. Academic Organizations and Institutions
- c. Other international organizations such as the Internet Engineering Task Force (IETF) and Internet Society's Interplanetary Networking Special Interest Group (IPNSIG)

Committee membership may be revisited to enhance participation by the liaison organizations based on expanding the IOAG's charter in June 2023.

4. Process

The Committee will follow a six-phase process to investigate, define, study, select, and ultimately recommend the appropriate governance structure option(s) for LunaNet and prepare the final recommendation(s) report on how to govern LunaNet. As part of the plan to carry out this study, a preliminary work plan was prepared where the tasks to be carried out were organized according to the study objectives and were assigned to phases of the CSLG process. Fig. 2 shows the CLSG process that the Committee will follow to conduct the LunaNet governance study.

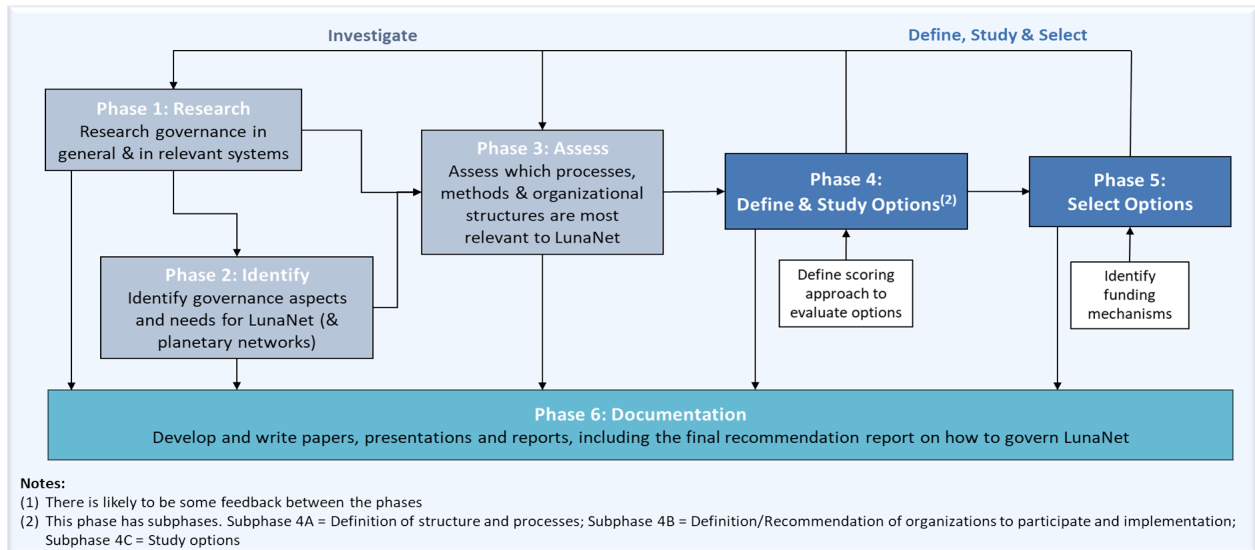


Fig. 2. CSLG Process

4.1 Phase 1

During Phase 1, the Committee will research different aspects of governance and the relevant systems where governance will apply. For example, different multi-stakeholder governance management frameworks/structures will be investigated, national, international, and regional coordination and collaboration processes to use and apply them, as well as processes to monitor and control LunaNet's governance management processes and cross-processes. It will also investigate whether LunaNet should make interface software and hardware open source, investigate current international and national multi-stakeholder organizations and entities to leverage their current roles in developing the governance structure, as well as about the governance of the Internet and the steps to transition LunaNet's governance from plan to implementation and from implementation to operation.

4.2 Phase 2

Phase 2 will consist of identifying the governance aspects and needs of LunaNet (and planetary networks). It will be necessary to identify the strengths and weaknesses of different multi-stakeholder governance management frameworks/structures, identify an organization to host and facilitate multi-stakeholder's discussions, identify how to handle governance aspects for private property rights, trans-border data rights, ownership, the dispute resolution process and venues for legal processes within the potential treaty framework, and how the communications governance structure for international treaties and agreements, national laws and regulations fit into a larger/broader framework for the engagement/involvement of other inter-governmental bodies and private sectors. It will also be necessary to identify whether networks other than LunaNet, including networks at other locations in the Solar System (i.e., Lagrange points, other planets) would fit into the governance structure. Other aspects of LunaNet's governance and needs will also be identified to carry out the study.

4.3 Phase 3

As seen in Fig. 2, Phase 1 and Phase 2 overlap as governance aspects can be identified in parallel as the research is carried out. The findings and results of Phase 1 and Phase 2 will be used for Phase 3, where the Committee will be able to assess which processes, methods, and organizational structures are most relevant to LunaNet. Examples of evaluation include evaluation of methods and organizational structures for complete and comprehensive governance management processes for organizational bodies necessary for the tasks required to provide the services and resolve/reach consensus on LunaNet decisions. Assessment of processes and methods for reaching agreements through space diplomacy, assessment of monitoring and control processes for LunaNet governance management processes, assessment of current international and national multi-stakeholder organizations and entities to build on their current roles in developing the governance structure. Assessment of the relationship with respect to the similarities and differences between LunaNet and the Internet (e.g., in functions, structure, organizational bodies, processes, architecture, services, etc.) to determine the areas of Internet governance that could be adopted by LunaNet.

4.4 Phase 4

Once the investigative part of Phases 1, 2 and 3 has been completed and the most relevant methods and organizational structures have been determined, different options can be defined and studied in Phase 4 using the results and findings of these previous phases. This phase will have three Subphases: Subphase 4A, 4B and 4C.

- Subphase 4A: This subphase will cover the definition of the structure and processes and will include the definition of the organizational structure departmentation to group its various activities based on the architectural aspects of LunaNet. Tasks will be carried out such as determining the reporting structure, process, and criteria for reporting status escalation of risks and issues for decision-making at the required level of the organizational structure departmentation. Definition of objectives, roles, responsibilities, functions/services for each organizational body within the structure will also be determined, as well as external entities/organizations that play a key role in achieving LunaNet's mission and vision. Multi-stakeholder governance activities will be considered and defined to resolve and reach consensus on recommendations and decisions that are used/employed accordingly within their government, business, and academic organizations and in different regions while adhering to international treaties, conventions, and regulations. The context/environment in which LunaNet operates will be defined considering national and international laws related to LunaNet's areas of interest (e.g., spectrum, internetworking, freedom of navigation, and items under objective 1d). This subphase will also consider defining how the organization's bodies will measure success using defined standards and metrics (e.g., defining metrics for risk and issue management, stakeholder engagement, stakeholder communication, etc.), and how the governance processes/requirements and organizational functions will tie together to achieve the LunaNet Guiding Principles.
- Subphase 4B: In this subphase the definition and recommendation of organizations to participate and implement the governance approach will be carried out. Flexibility will be provided within the organizational governance structure definition to expand and add additional members and/or liaisons, by inviting other organizations as necessary, to participate in the LunaNet governance definition. Organizations/stakeholders with their respective functions and services, roles, objectives, and goals in LunaNet will be defined and determined, including when they will play an important/key role based on architectural phase or time frame, and in which organizational body of the governance management structure will participate in LunaNet. As part of the implementation tasks, an implementation roadmap, and a schedule for regular reviews of the governance model will be defined and recommended. For regular reviews, it should be defined how to examine the components of the governance model in terms of how they will be working for the organizational body in action, and the respective plan. These reviews should make it possible to determine any other implementation efforts that may be beneficial.
- Sub-Phase 4C: In this subphase is where the different options defined in Sub-Phase 4B will be studied and evaluated to select the best framework/structure and/or approach for LunaNet. As part of this effort, the scoring approach for evaluating these options will be defined.

4.5 Phase 5

After evaluating the options, the selection of options can be made to recommend the best approach or approaches for the governance of LunaNet. This selection process will take place in Phase 5 and, as part of this process, the identification of funding mechanisms for the recommended structure and the development of cost estimates for organizational options based on the resource requirements of the organizations that must be involved to establish/operate the governance of LunaNet will be carried out. If as part of this process it is recommended to modify the scope of an existing organization or recommend the establishment of a new organization that does not currently exist, consideration should be given to how to provide resources and possible funding mechanisms for that proposed organization and/or new element(s).

4.6 Phase 6

Phase 6 is related to the documentation that will take place during the governance study process for LunaNet. This phase will include the development of internal and external reports, papers, and presentations that will be generated during the study, including the final report of recommendations on how to govern LunaNet. Internal reports will be made at the end of each phase with the findings and results thereof to be used as a reference and continue to the next phase. The CSLG process provides an aspect of feedback in the event that the results of one phase cause previous phases to be reviewed for refinement, to assist in the development of the final report of recommendations on how to govern LunaNet. Some examples of documentation will include the definition of how communication and coordination/collaboration within and between the organizational bodies of the architectural aspects for space internetworking (lunar relay network, surface network, Earth network, interconnection between them), physical layer links (spectrum), security, protocols, and standards, and the process and involvement of other external entities/organizations will be addressed. In addition, the recommendations of the organizational

framework/structure will be included, using the best option/approach of a multi-stakeholder model, this being represented through a governance structure diagram outlining and describing handoffs and connecting mechanisms between the organizational bodies of LunaNet and other (external) organizations.

5. Conclusion

To accomplish the purpose of this study, the Committee will consult with subject matter experts from stakeholder organizations and other organizations as required. This includes fields such as CPNT and other disciplines of engineering, law, organizational design, and governance. The results, findings and an explanation of the study's recommendations and definitions will be provided in a final report that will define and recommend how to establish and operate the governance of LunaNet, while meeting the objectives of the study in accordance with the architectural and process guiding principles that will be used by the Committee in their decisions related to the governance of LunaNet.

Success factors and indicators have been developed where stakeholder organizations participating in the Committee are invested in the success of the Committee and will therefore require periodic evidence of ongoing efforts. In terms of resources, IOAG will provide the administrative support for Committee's meetings and the Committee will be funded by Committee stakeholders who contribute resources (primarily personnel) and other voluntary contributions, such as accommodations for in-person meetings. The timeframe for completing the study has not yet been determined, as a schedule for the study is still being developed.

Please contact the authors to provide feedback and express an interest in participating in the study.

Acknowledgements

The research that was carried out at the Jet Propulsion Laboratory, California Institute of Technology, was performed under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

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