The Road Ahead: From Cislunar PNT to the Solar System Internet

Workshop on Cislunar PNT, 11 - 13 February 2025, Vienna, Austria

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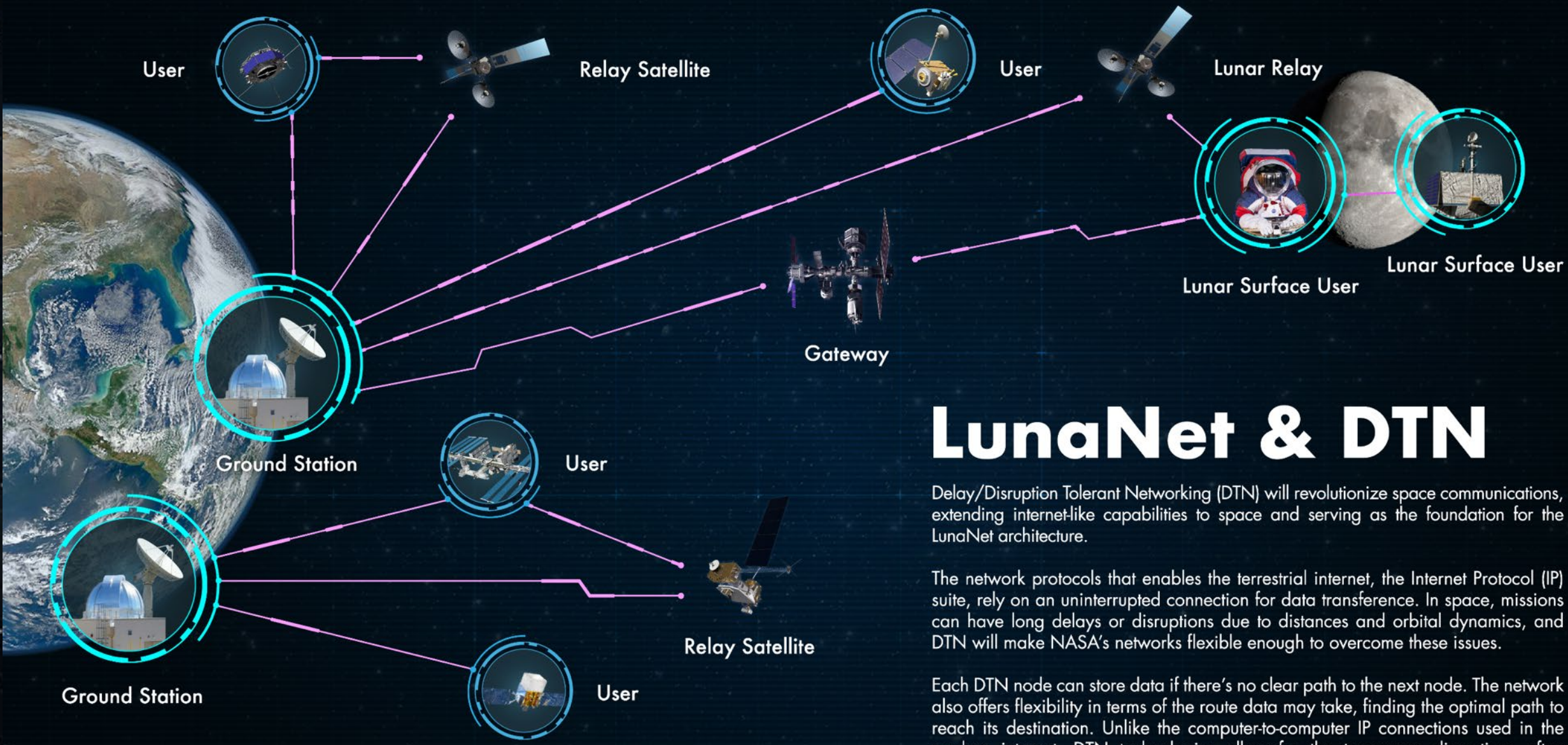
The Work of Cislunar PNT Today Can Pave the Way for a Solar System Internet Tomorrow

Current Efforts

- IOAG – space communications and space agencies
- ICG – global navigation satellite systems and their providers
- SFCG – space spectrum among space agencies
- National policies on lunar time and reference frames
- CCSDS – lunar interoperability forum
- Use of Delay-Tolerant Networking and Bundle Protocols in space
- Internet Society Interplanetary Network Special Interest Group (IPNSIG)

Near-future Developments

- ITU World Radiocommunications Conference
  - Spectrum allocation for lunar comm/PNT
- Development of lunar time and geodetic standards
- Joint IOAG-ICG Workshops on Cislunar PNT
- UN COPUOS Action Team on Lunar Activities Consultation
  - Artemis and ILRS signatories
- Internet Governance Forum
  - Multistakeholder discussions for a solar system internet



*Conceptual visualization. Not meant to show actual present or future network architecture. Not to scale.

LunaNet & DTN

Delay/Disruption Tolerant Networking (DTN) will revolutionize space communications, extending internet-like capabilities to space and serving as the foundation for the LunaNet architecture.

The network protocols that enables the terrestrial internet, the Internet Protocol (IP) suite, rely on an uninterrupted connection for data transference. In space, missions can have long delays or disruptions due to distances and orbital dynamics, and DTN will make NASA's networks flexible enough to overcome these issues.

Each DTN node can store data if there's no clear path to the next node. The network also offers flexibility in terms of the route data may take, finding the optimal path to reach its destination. Unlike the computer-to-computer IP connections used in the modern internet, DTN technologies allow for the temporary disruptions often experienced by spacecraft far from Earth.

Enabling Lunar PNT: International Committee on GNSS (ICG)—A GNSS Interoperability Powerhouse

The United Nations ICG consists of the GNSS Service Providers Forum and four Working Groups (WG-S, WG-B, WG-C and WG-D).

WG-S
Systems, Signals and Services

Major Topics
- Spectrum compatibility
- Interference detection & mitigation
- Service interoperability
- Performance standards & monitoring

WG-B
Enhancement of GNSS
Performance, New Services and Capabilities

Major Topics
- Development of interoperable, multi GNSS SSV
- GNSS hosted search and rescue payloads
- Space weather and atmosphere modelling

Applications Subgroup

Space Use Subgroup (SUSG)

The WG-B SUSG is the body dedicated to representing needs of space users within ICG, including lunar
Work Plan includes Work Packages WP1–WP5.

WG-D
Geodetic Reference, Time Reference and Applications

Major Topics
- ITRF, geodetic reference frame
- Time standards & multi constellation time offsets
- High Accuracy applications (PPP)

WG-C
Information Dissemination and Capacity Building

Major Topics
- Training and Seminars
- Information Material

Artemis Accords

- Section 5 of the Artemis Accords calls for interoperability across all partners. “The Signatories recognize that the development of interoperable and common exploration infrastructure and standards, including but not limited to fuel storage and delivery systems, landing structures, **communications systems**, and power systems, will enhance space-based exploration, scientific discovery, and commercial utilization. The Signatories commit to use reasonable efforts to **utilize current interoperability standards** for space-based infrastructure, to **establish such standards when current standards do not exist or are inadequate**, and to follow such standards.”
- NASA currently does not have one set of definitions for what constitutes “cislunar” space. Additionally, the defined GNSS space service volume is not tied to the cislunar term. The relationship of interplanetary internet domains to physical domains is a likely topic for discussion among Accord signatories, starting with decisions by LunaNet.
    - Platforms in near Earth orbit may be part of the Earth domain while Lunar Gateway and lunar surface operations are part of the Moon domain. Sub-regions of the Moon domain could include shadowed craters and underground tunnels not directly accessible to communications from Earth.

Potential Technical Cooperation Issues for Cislunar PNT

Cislunar PNT foundations being built now

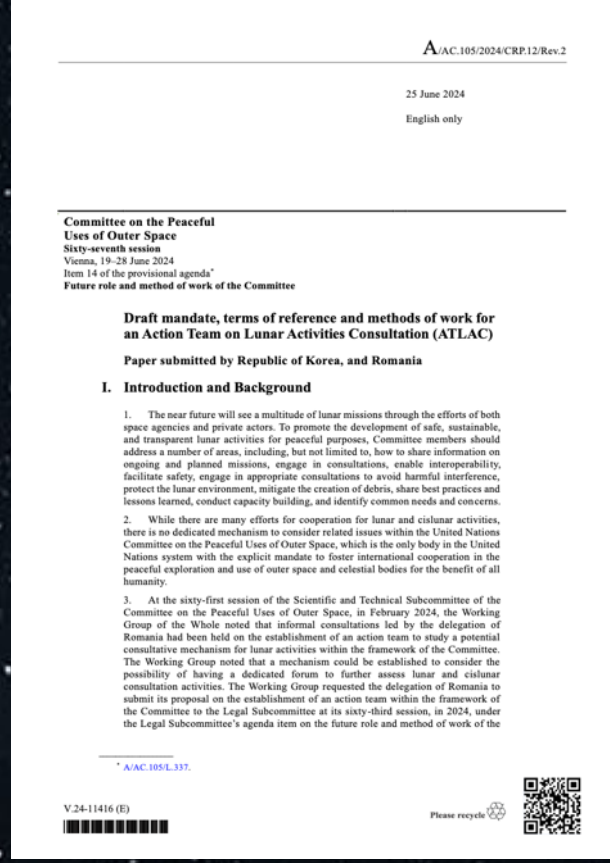
- Queqiao-1 relay satellite launched in 2018 and operating past its initial 5 year design life.
- Queqiao-2 launched in 2024 and operating.
- NASA to launch its first LunaNet relay on Intuitive Machine's IM-2 CLPS mission this month (February 2025)
- ESA to launch its first LunaNet relay in late 2025: Surrey Satellite's Lunar Pathfinder
- LunaNet should be operational in time for WRC-27
- Studies to improve lunar RF propagation models on-going

Potential Issues identified by the IOAG

- Is there a lunar SSA mechanism to exchange ephemerides and almanacs among service providers?
- Will there be a single interoperable service or distinct compatible (non-interfering) services for lunar nav broadcasts?
- Are orbits coordinated among services providers just to ensure compatibility or maximize lunar PNT accuracy and availability?
- How are ITU allocated bands shared by separately authorized services to avoid harmful RFI?
- For signals using the same frequency, how are pseudo-random noise (PRN) codes allocated to service providers?
- For networking, are frame IDs and subframe PNT-related fields allocated among service providers are done separately by each provider?

International Governance of Cislunar PNT

- **Current international space law and ITU regulations apply**
  - Cislunar PNT is part of space-to-space RNSS in NGSO orbits
- Some discussions are occurring today among national space agencies and national spectrum administrations
- The Intergovernmental Agreements for the ISS (including Gateway) do not extend to the lunar surface. ILRS mechanisms still in work.
- Given the increasing complexity of space operations at the Moon, a new mechanism is needed for safe and responsible operations.
  - Multilateral, not just bilateral or regional
  - At the level of sovereign states, not just space agencies
- **UN COPUOS approved a draft mandate for an Action Team on Lunar Activities Consultation (ATLAC) in June 2024**
  - Modeled on the long-standing International Committee on GNSS (ICG)
  - Reports to parent body COPUOS, then UN 4th Committee
  - Non-binding focus on improving technical transparency
  - Many potential topics beyond cislunar PNT (e.g., lunar SSA, safety frequencies, sizes of landing zones, debris mitigation, etc.)



A/AC.105/2024/CRP.12/Rev.2

25 June 2024

English only

Committee on the Peaceful Uses of Outer Space
Sixty-seventh session
Vienna, 19–28 June 2024
Item 14 of the provisional agenda*
Future role and method of work of the Committee

Draft mandate, terms of reference and methods of work for an Action Team on Lunar Activities Consultation (ATLAC)

Paper submitted by Republic of Korea, and Romania

I. Introduction and Background

1. The near future will see a multitude of lunar missions through the efforts of both space agencies and private actors. To promote the development of safe, sustainable, and transparent lunar activities for peaceful purposes, Committee members should address a number of areas, including, but not limited to, how to share information on ongoing and planned missions, engage in consultations, enable interoperability, facilitate safety, engage in appropriate consultations to avoid harmful interference, protect the lunar environment, mitigate the creation of debris, share best practices and lessons learned, conduct capacity building, and identify common needs and concerns.

2. While there are many efforts for cooperation for lunar and cislunar activities, there is no dedicated mechanism to consider related issues within the United Nations Committee on the Peaceful Uses of Outer Space, which is the only body in the United Nations system with the explicit mandate to foster international cooperation in the peaceful exploration and use of outer space and celestial bodies for the benefit of all humanity.

3. At the sixty-first session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space, in February 2024, the Working Group of the Whole noted that informal consultations led by the delegation of Romania had been held on the establishment of an action team to study a potential consultative mechanism for lunar activities within the framework of the Committee. The Working Group noted that a mechanism could be established to consider the possibility of having a dedicated forum to further assess lunar and cislunar consultation activities. The Working Group requested the delegation of Romania to submit its proposal on the establishment of an action team within the framework of the Committee to the Legal Subcommittee at its sixty-third session, in 2024, under the Legal Subcommittee's agenda item on the future role and method of work of the

* A/AC.105/L.337.

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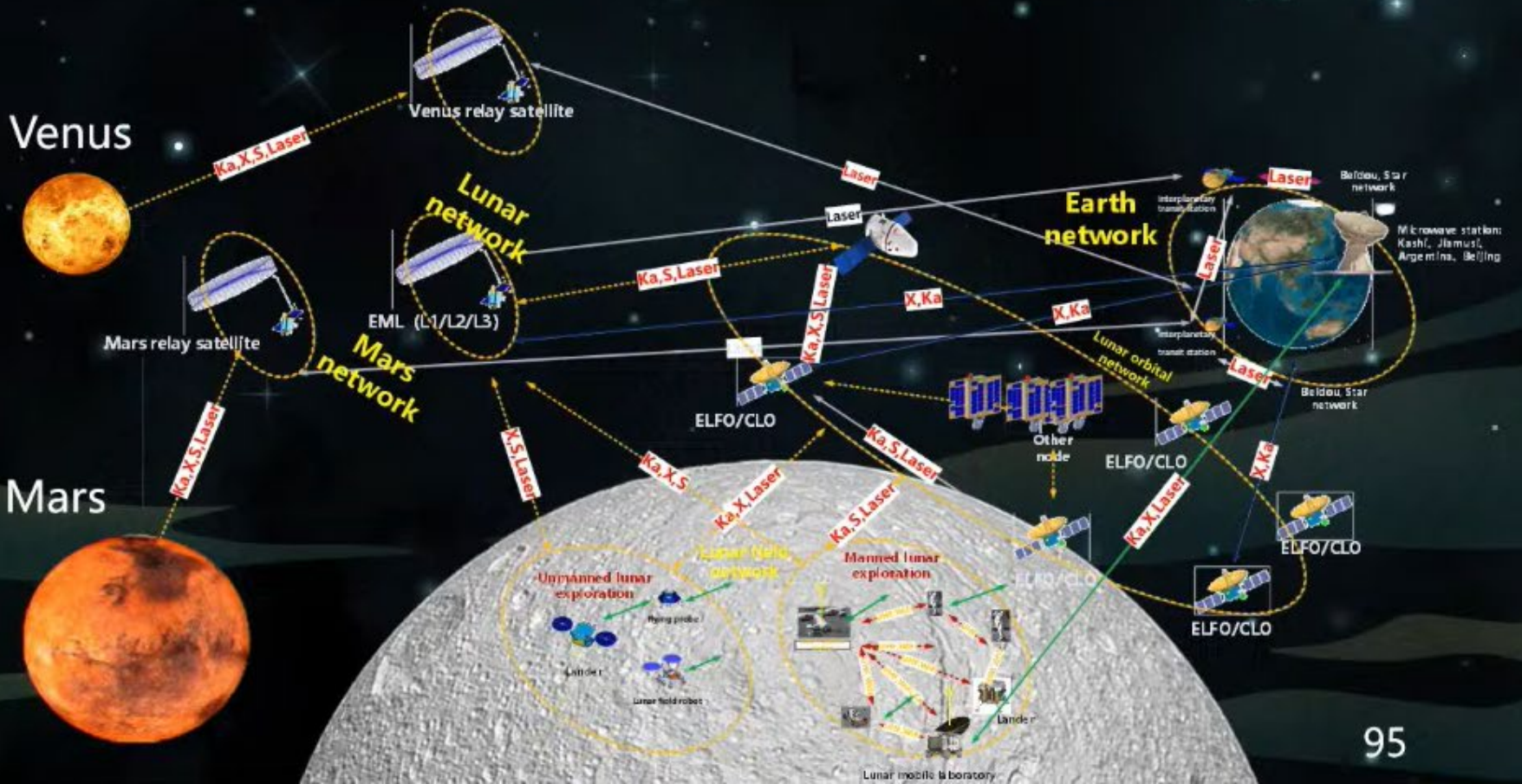
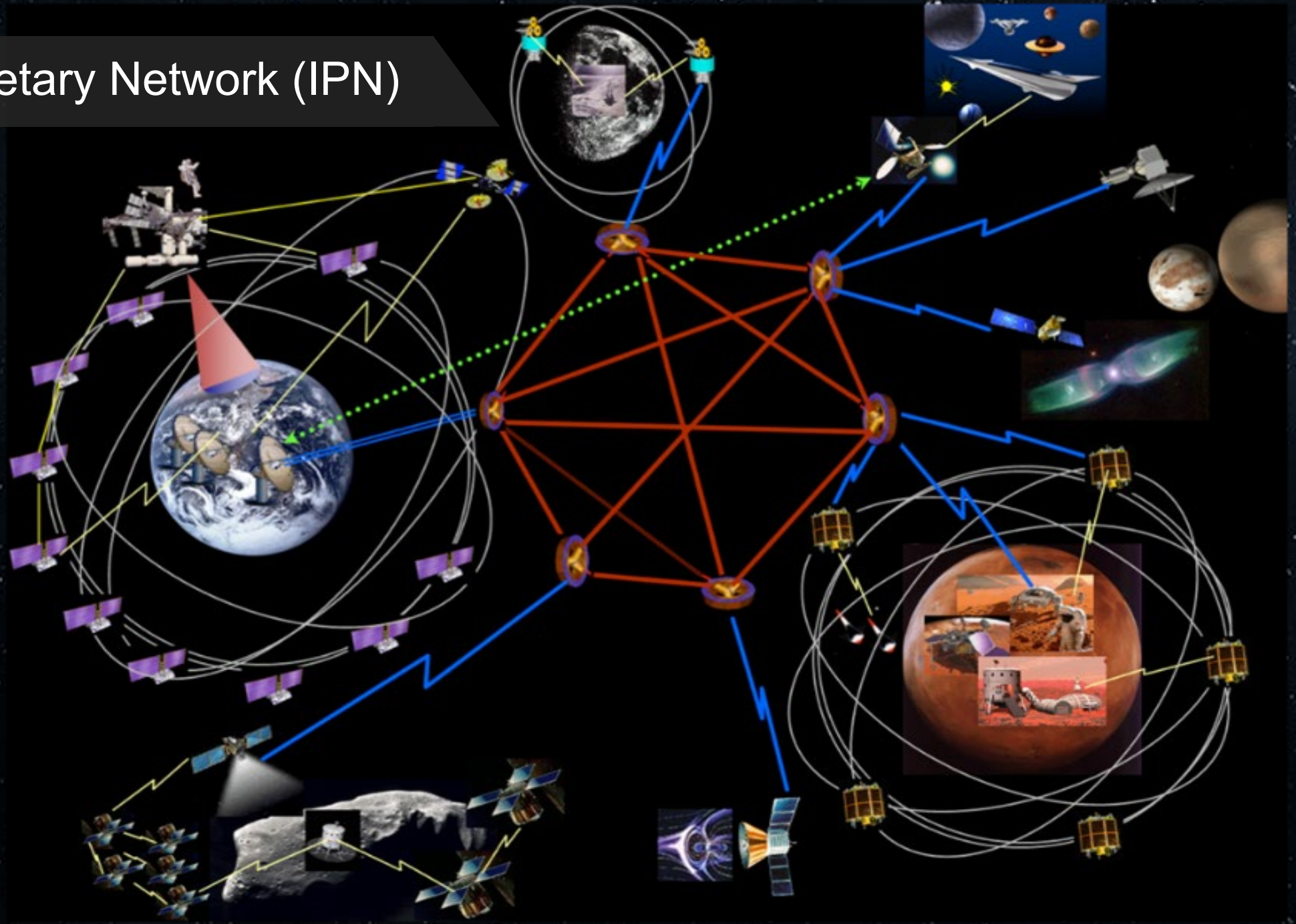
Queqiao V3.0

Overall objective: Build the basic type of deep space communication and navigation system to achieve Mars and Venus communication and navigation coverage.

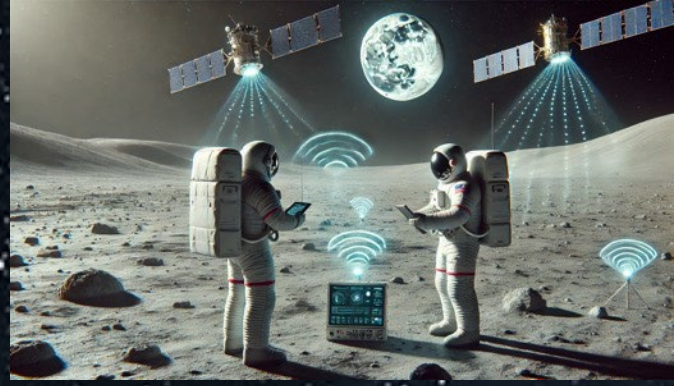
- **QQNet basic components**
  Lunar network, Mars network, Venus network.
  Each network can be connected to the Earth through interplanetary staging stations network interconnection (including BeiDou, Star network, etc).
- **Coverage capacity**
  Achieve quadruple coverage for the whole Moon.
  Achieve Mars and Venus communication and navigation coverage.
- **Composition of Earth-Moon-Mars core network**
  Earth main nodes: interplanetary staging stations.
  Lunar Main Node: EML Satellite.
  Mars Main Node : Mars Relay Satellite.
  Venus Main : Venus Relay Satellite.
  Interconnection through high-speed lasers:



Interplanetary Network (IPN)



Where are we going?



Decisions on Cislunar PNT are creating the technical foundations and identifying the governance issues that can enable a Solar System Internet (SSI)

- RF spectrum allocations, expansion of optical communications technology
- Lunar and solar system time and geodetic standards
- Expanding DTN-BP use and more than one lunar navigation service provider
- Multistakeholder engagement by Industry and academia on Internet experiences
  - New technical groups may emerge as with the terrestrial internet
    - Lunar PNT Frame IDs and sub-frame networking with lunar communications
    - IP addresses and ASN deconfliction, off-Earth node numbers and names
- Multilateral coordination of lunar operations
  - Artemis Accords and ILRS principles, cross recognition agreements
  - SFCG, CCSDS, IOAG, ICG, UN ATLAC?

No Single International Forum for Cislunar PNT

- Within the United Nations system
  - ITU – can handle multiple stakeholders, but has a limited space charter
  - COPUOS – broad space charter, but multilateral focused
  - Internet Governance Forum – multi-stakeholder but not PNT or space (yet)
- Project agreements
  - The ISS IGA does does not extent to lunar surface . What should Artemis partners and Accord signatories do?
  - Analogies exist in other fields for specific projects, e.g. CERN and ITER (with mixed success)
- Treaties from other domains
  - An Antarctic Treaty System for the Moon?
  - An ICAO for space (sovereignty issues are different from space)
- Potential new structures
  - A Space Guard function similar to the Coast Guard for safety of navigation, national regulatory enforcement, and rescue missions (e.g., the 1968 Agreement on Rescue and Return of Astronauts)

<u>Recommendations</u>

- Use both ITU and COPUOS for now
- Provide ”bottom up” technical input to multilateral forums, seek consensus on standards and best practices, and incorporate into national law and regulation for enforcement
- For cislunar PNT, like terrestrial PNT, ensure compatibility and seek interoperability where possible
- Promote multi-stakeholder, voluntary governance for coordination and cooperation like the internet

Backup

WRC-27 Agenda Item on Lunar / Cis-lunar Spectrum Use

As agreed at World Radio Conference 2023 (WRC-23) which concluded on 15 December 2023

WRC-27 Agenda Item 1.15 (ITU-R Resolution 680):
"to conduct studies on the spectrum needs and regulatory measures for possible new allocations and/or identifications, with any needed regulatory provisions, to support communication systems located on the lunar surface or in the lunar orbit in the frequency bands 390-450 MHz, 2 400-2 700 MHz, 3 500-3 800 MHz, 5 150-5 925 MHz, and 25.25-28.35 GHz, and to study a potential regulatory framework for future lunar communications"

Studies are being led by International Telecommunications Union (ITU) Working Party 7B (first meetings of WRC-27 cycle took place in Mar and Sep 2024)

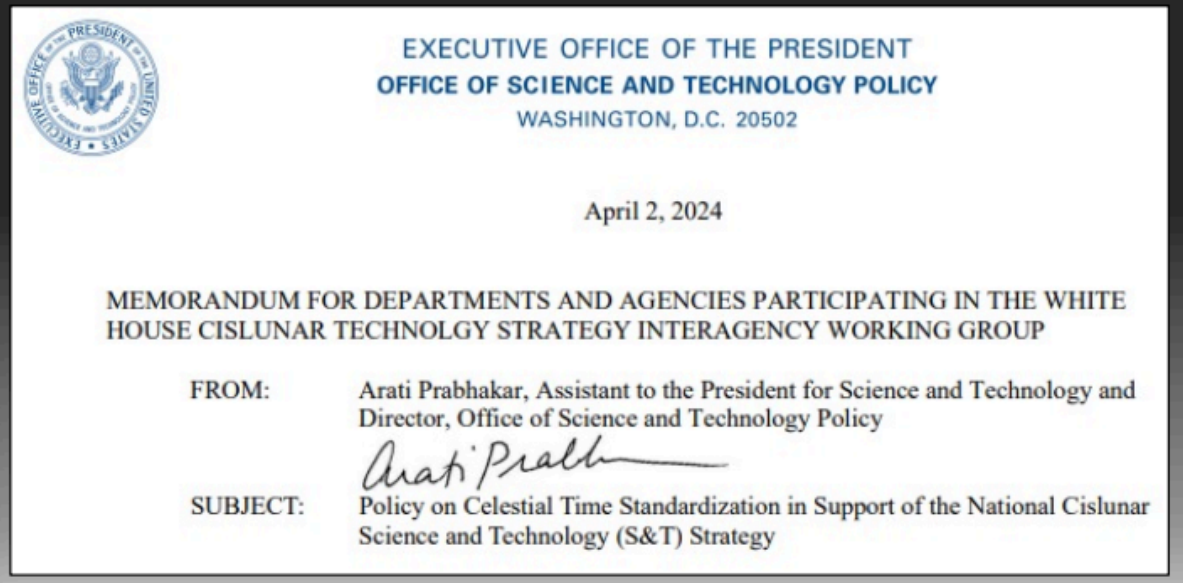
https://www.itu.int/wrc-23/

OSTP Policy Guidance for LTC Development

"Coordinated Lunar Time (LTC) will act as the established standard to enable Cislunar operations and maintain traceability to UTC."

"NASA, in coordination with the Departments of Commerce, Defense, State, and Transportation, will study, define, and implement a Coordinated Lunar Time (LTC) to support the gradual establishment of lunar infrastructure."

- NASA, with support from partnering departments and agencies, will establish the approach to LTC as the international standard *through existing standards bodies.*
- NASA will consider LTC as part of its annual Moon-to-Mars Architecture Concept Review cycle no later than December 31, 2024.
- NASA will provide a finalized strategy to the Executive Office of the President to implement lunar timing standardization no later than December 31, 2026.



EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

April 2, 2024

MEMORANDUM FOR DEPARTMENTS AND AGENCIES PARTICIPATING IN THE WHITE HOUSE CISLUNAR TECHNOLGY STRATEGY INTERAGENCY WORKING GROUP

FROM: Arati Prabhakar, Assistant to the President for Science and Technology and Director, Office of Science and Technology Policy

SUBJECT: Policy on Celestial Time Standardization in Support of the National Cislunar Science and Technology (S&T) Strategy

https://www.whitehouse.gov/wp-content/uploads/2024/04/Celestial-Time-Standardization-Policy.pdf

Academy materials at:

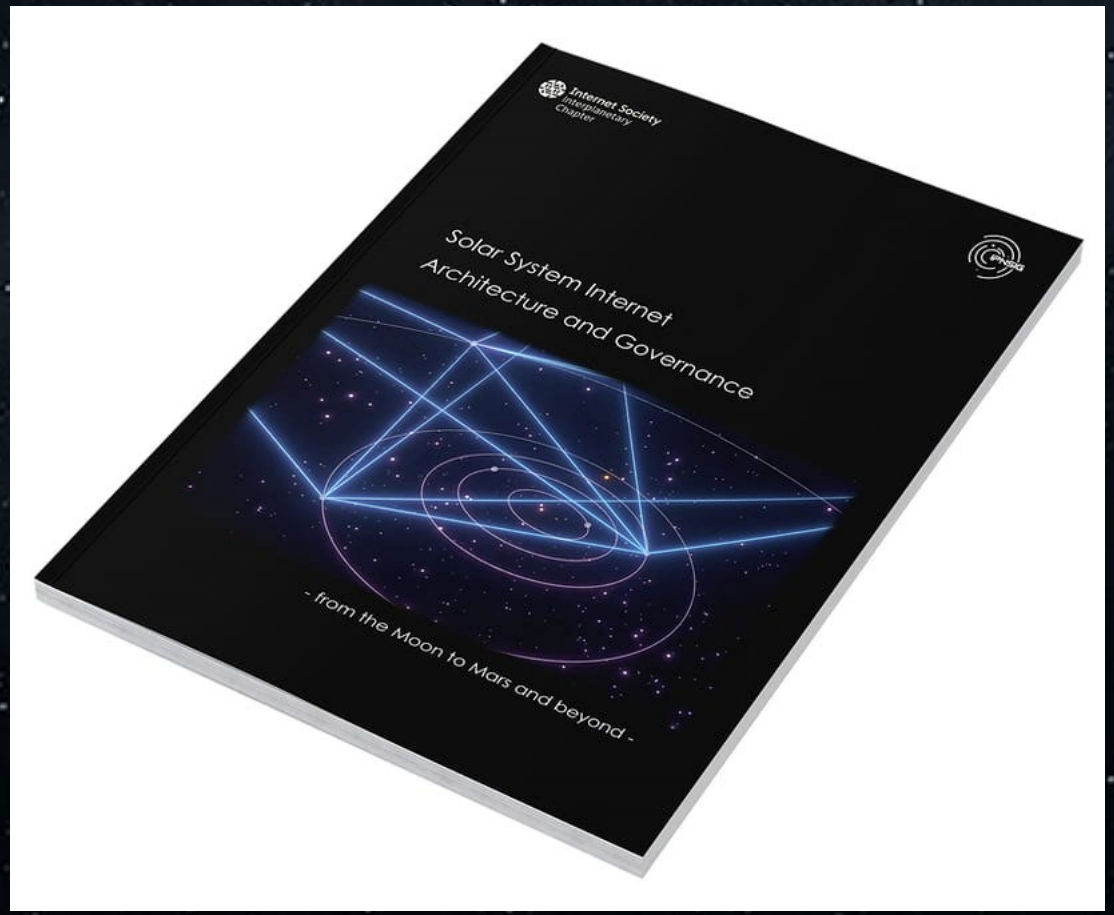
➡ *https://ipnsig.org/ipnsig-academy-events/*

IPNSIG ACADEMY

Any questions to:

➡ *secretariat@ipnsig.org*

IPNSIG Report on Solar System Internet Architecture and Governance



Solar System Internet Evolution