



LunaNet Overview and Interoperability for Lunar PNT

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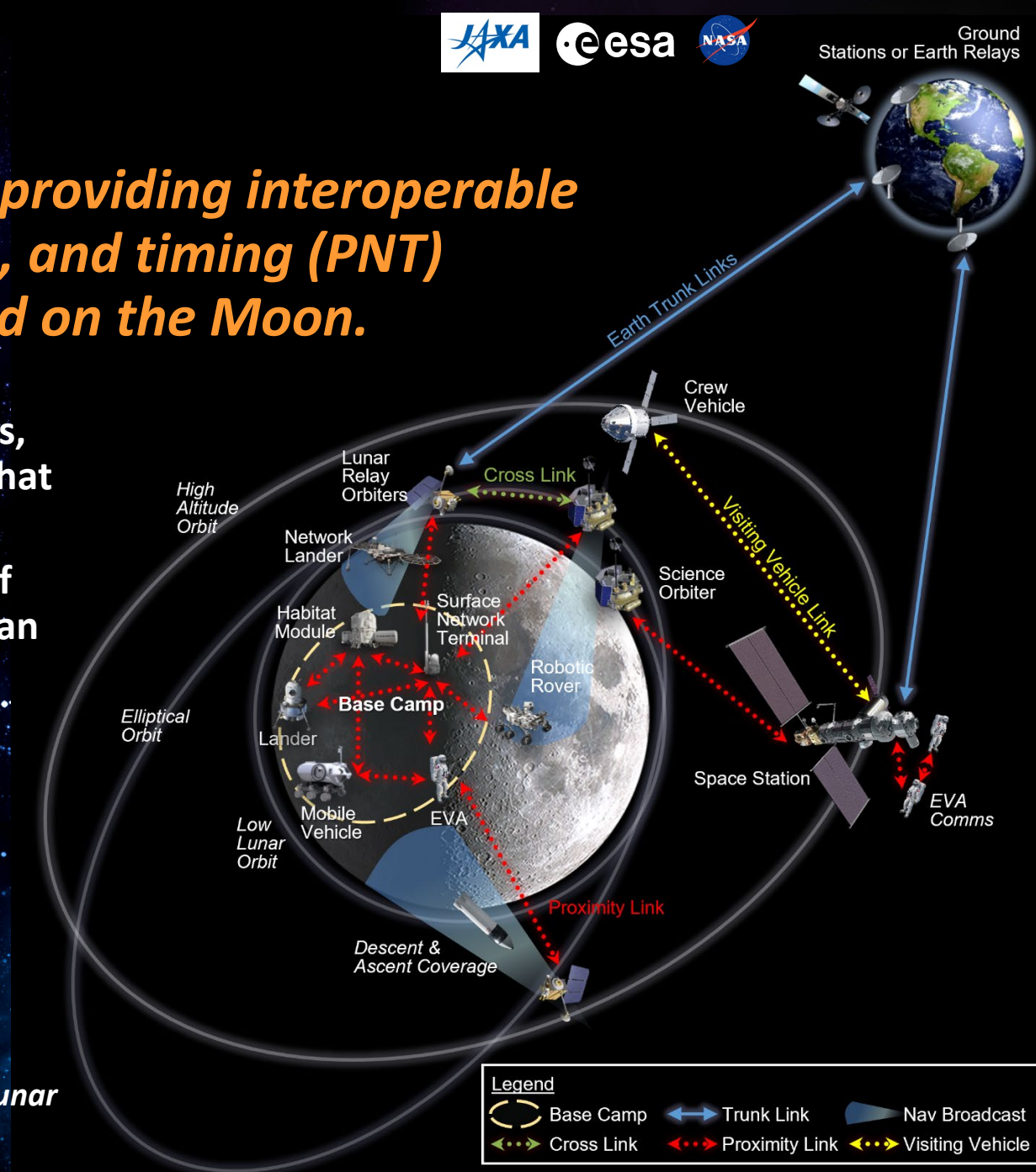
- LunaNet
- LunaNet Interoperability Specification
- LunaNet PNT Services
- LunaNet Service Provider Updates

What is LunaNet?

LunaNet is a set of cooperating networks providing interoperable communications and position, navigation, and timing (PNT) services for users in transit to, around, and on the Moon.

- Based on a framework of mutually agreed-upon standards, protocols, frequency bands, and interface requirements that enable interoperability.
- Allows many lunar mission users to engage the services of diverse commercial and government service providers in an open and evolvable architecture.
 - Service-Oriented
 - Scalable
 - Open
 - Resilient
 - Secure
 - Extensible

LunaNet consists of Earth Ground Stations (for Direct with Earth links), lunar orbital relays (lunar proximity and Earth trunk links), and surface assets:



Lunar Systems Relationships



LunaNet

Framework for Standardized Interoperable Services,
umbrella under which many providers collectively work.
Interoperability defined in a set of *specifications*.

Lunar Comm. Relay and Navigation System (LCRNS)

NASA's instantiation of LunaNet
Lunar Relay Services– a LunaNet
Service Provider (LNSP)

Currently scoped for Initial
Operating Capability

Moonlight Lunar Communication s and Navigation System (LCNS)

ESA's instantiation
of Lunar Relay
Services

Lunar Navigation Satellite System (LNSS)

Japan's
instantiation
of Lunar Relay
Services

Ground Stations for Lunar Missions

e.g. NASA's
Lunar
Exploration
Ground
Segment

Others

e.g. other orbiting systems,
surface comm and/or PNT
systems (future), ground
systems, users

Lunar Reference System(s) Components (includes Time)

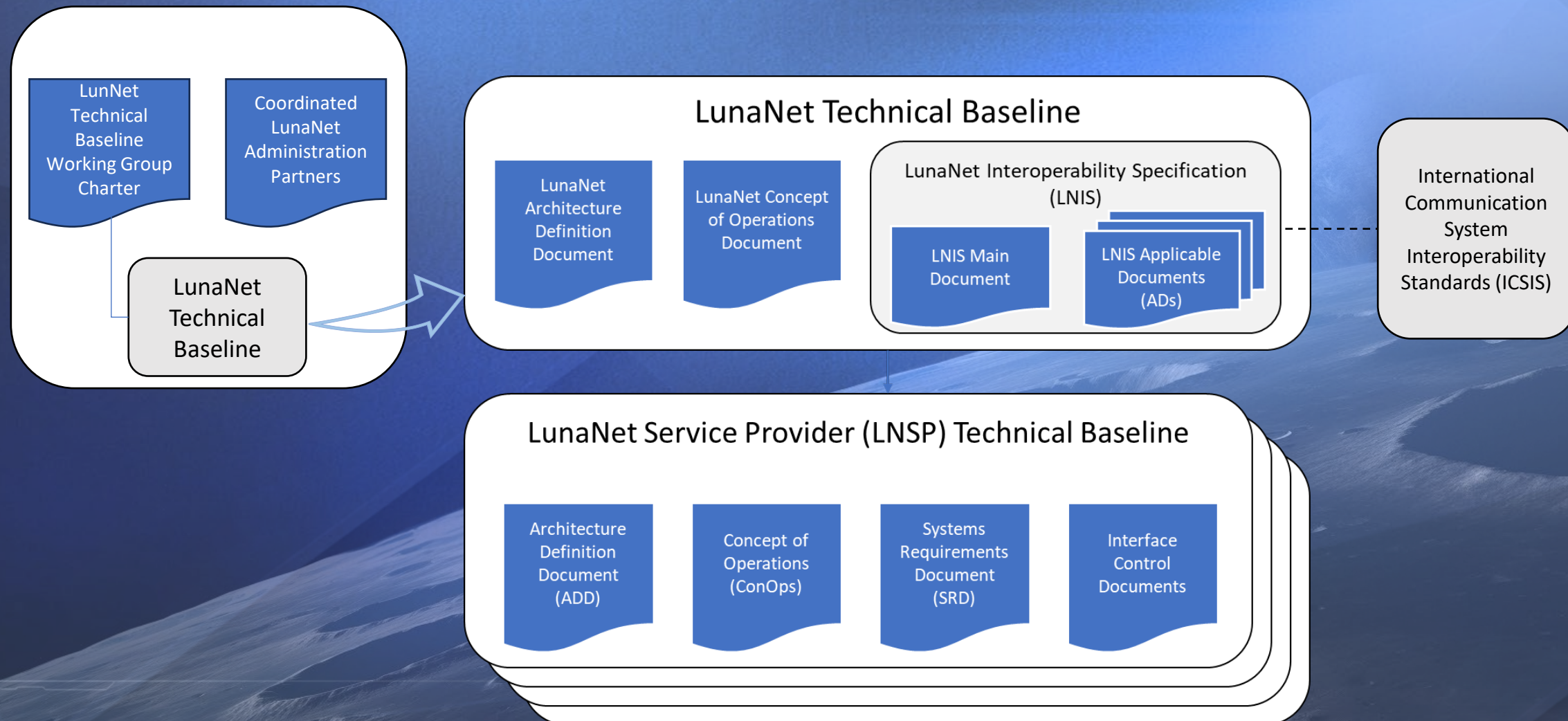
A canonically
defined set of
components for
consistent, accurate,
and safe navigation.

Interoperability
defined in Applicable
Document 5 (AD5).

LunaNet Technical Baseline



LunaNet Interoperability Specification (LNIS) is part of the LunaNet Technical Baseline set of documents.



LunaNet Interoperability Specification



LunaNet Interoperability Specification (LNIS)

- A set of mutually agreed-upon specifications of standards, protocols, and interface requirements that enable interoperability.
- Provides a basis for operation of a network capable of interoperating with other LNIS-compliant networks.
- Being developed cooperatively with international partners through the LNIS Working Group.
- **Besides the main document, includes a set of Applicable Documents:**
 - AD1 Volume A LunaNet Signal-In-Space Recommended Standard (LSIS) Augmented Forward Signal (AFS)
 - AD1 Volume B LunaNet Signal-In-Space Recommended Standard (LSIS) Point-to-Point Signals
 - AD2 LunaNet Measurement Schema and Parameters
 - AD3 LunaNet Detailed Message Definition Document
 - AD4 LunaNet Location Services for Users (not LunaNet 1.0)
 - AD5 Lunar Reference System and LunaNet Reference Time System Standard
 - AD6 LunaNet Data Services Document
 - AD7 LunaNet LunaSAR Definition Document (not LunaNet 1.0)
 - AD8 LunaNet Interoperability Security Specifications

LNIS v5

LunaNet Interoperability Specification Document

Version 5

APPROVED

AD1 Vol A, LSIS-AFS v1

LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LSIS - AFS) VOLUME A

Version 1

Noted as Applicable Document 1 [AD1 Vol-A] in LNIS V5

Augmented Forward
Signal is the broadcast
service that offers PNT.

LunaNet Interoperability Specification

Status



- LNIS Draft Version 5 *and* Applicable Document-1 Volume A, LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal*
 - Dispositioned >500 public comments from space agencies, industry, and organizations;
 - Documents focus on agreed-upon near-term needs for required services, termed LunaNet 1.0;
 - Matures broadcast Augmented Forward Signal (AFS) definition;
 - Identifies select Point-to-Point and Direct With Earth signals;
 - Includes Data Services and a matured Service Access;
 - Consistency with document that defines user side of interface.
- Publication Feb 2025.
- Future LNIS update to complete LunaNet 1.0 specification to cover near term needs.



South Pole Region
Service Volume

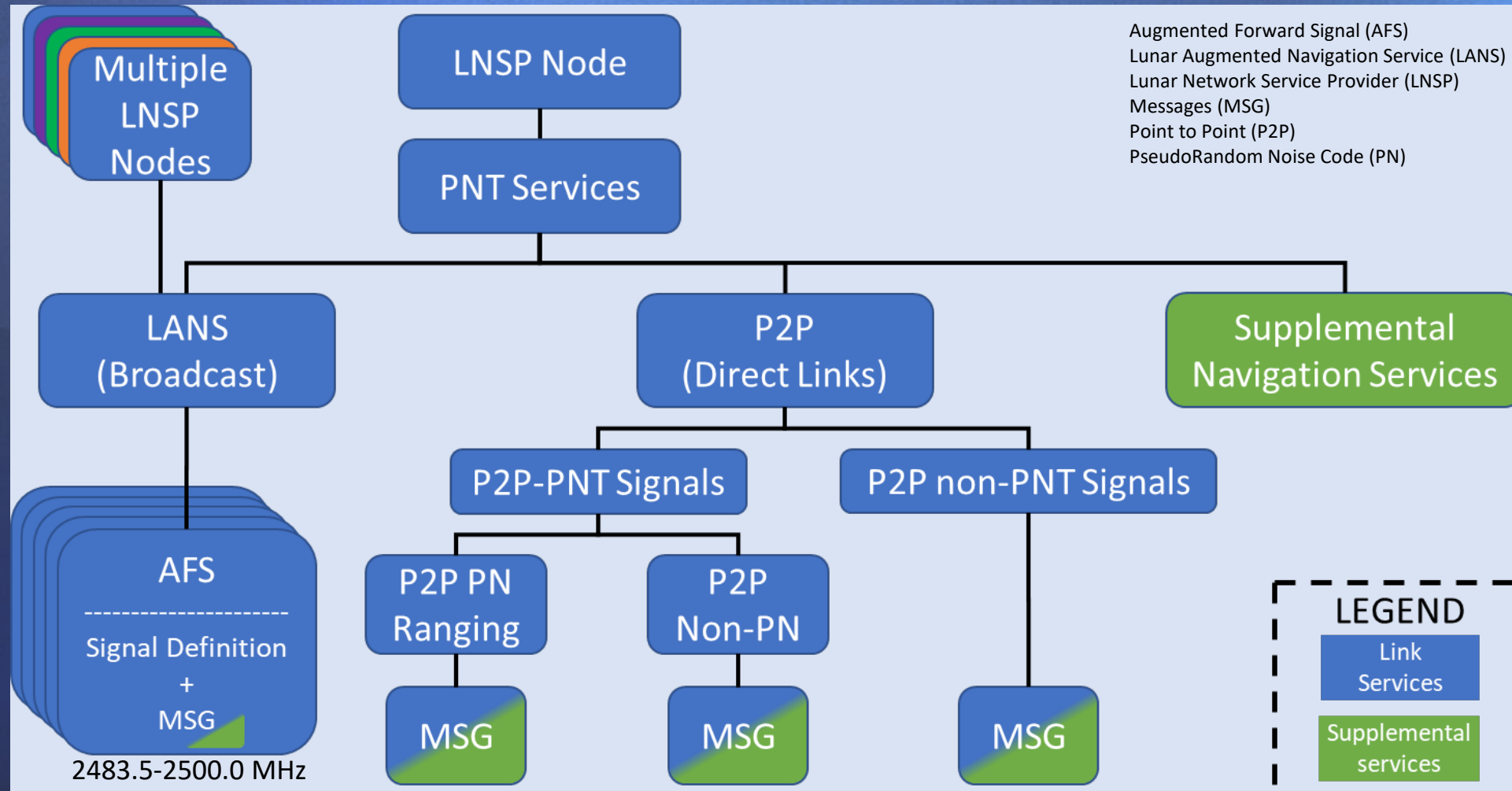
LNIS version 5 and LSIS-AFS version 1 are available online.

https://www.nasa.gov/directorates/somd/space-communications-navigation-program/lunanet-interopability-specification/#_blank

* Technical paper and presentation available in ION ITM 2025 proceedings:
<https://www.ion.org/itm/abstracts.cfm?paperID=15014>



LunaNet Framework PNT Services



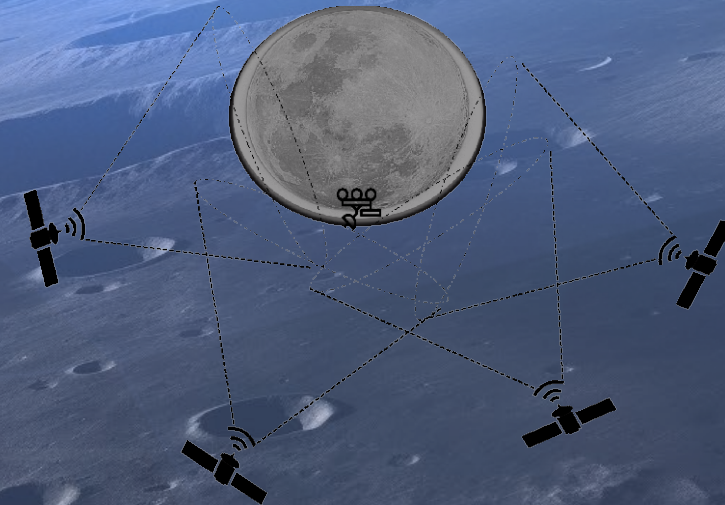
PNT Services rely on definition, adoption, and maintenance of common lunar geodetic reference and time systems.

LunaNet PNT services:

1. Proximity:
 - a. Point-to-Point navigation services (direct link between the user and the provider); PNT-over-Comm
 - b. Lunar Augmented Navigation Service (LANS)
2. Direct With Earth
3. LunaNet Interoperability Spec responsible for defining signal designs, Signal in Space Error, messages for interoperable services.
4. Reliant on definition and maintenance of lunar reference geodetic and time systems.

LANS characteristics:

- A lunar analog to terrestrial GPS/GNSS with associated benefits from broadcast signals and messages.
- The concept is to achieve maximum reuse of GNSS techniques and technologies.
- Defines a Lunar Service Volume (LSV) that extends beyond the local lunar surface region.
- This proximity service is provided from multiple providers nodes to multiple users at the same time.



Interoperability is Critical to LANS



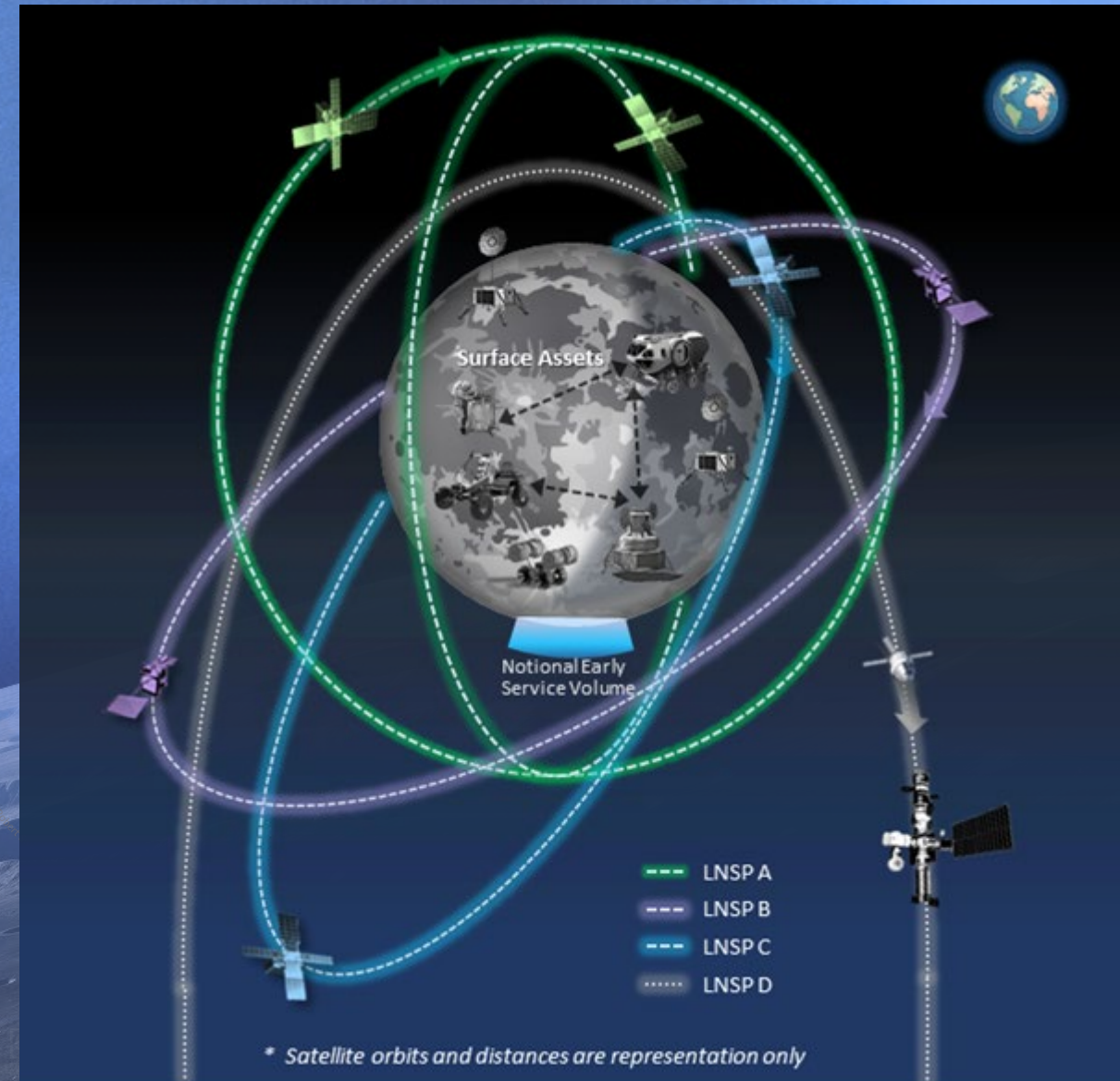
Current concept is to combine different LunaNet Service Provider (LNSP) space vehicles to create a constellation of AFS broadcasters for LANS.

➤ Interoperability is critical to achieve this.

LANS Interoperability¹: each service provider that claims to be LunaNet compliant (becoming a LunaNet Service Provider, LNSP) for the LANS service, must:

- Comply with a common signal and message structure (Augmented Forward Signal, AFS).
- Comply with the Signal In Space Error requirements.
- Assure compliance with the Power at the Surface requirement.

¹ ICG SSV booklet: "(interoperability is defined as) the ability of global and regional navigation satellite systems, and augmentations and the services they provide, to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system"



AFS Parameters (per AD-1 Vol A)



Carrier Center Frequency → 2492.028 MHz; Frequency Band → 2483.5 MHz to 2500.0 MHz; Polarization → RHCP

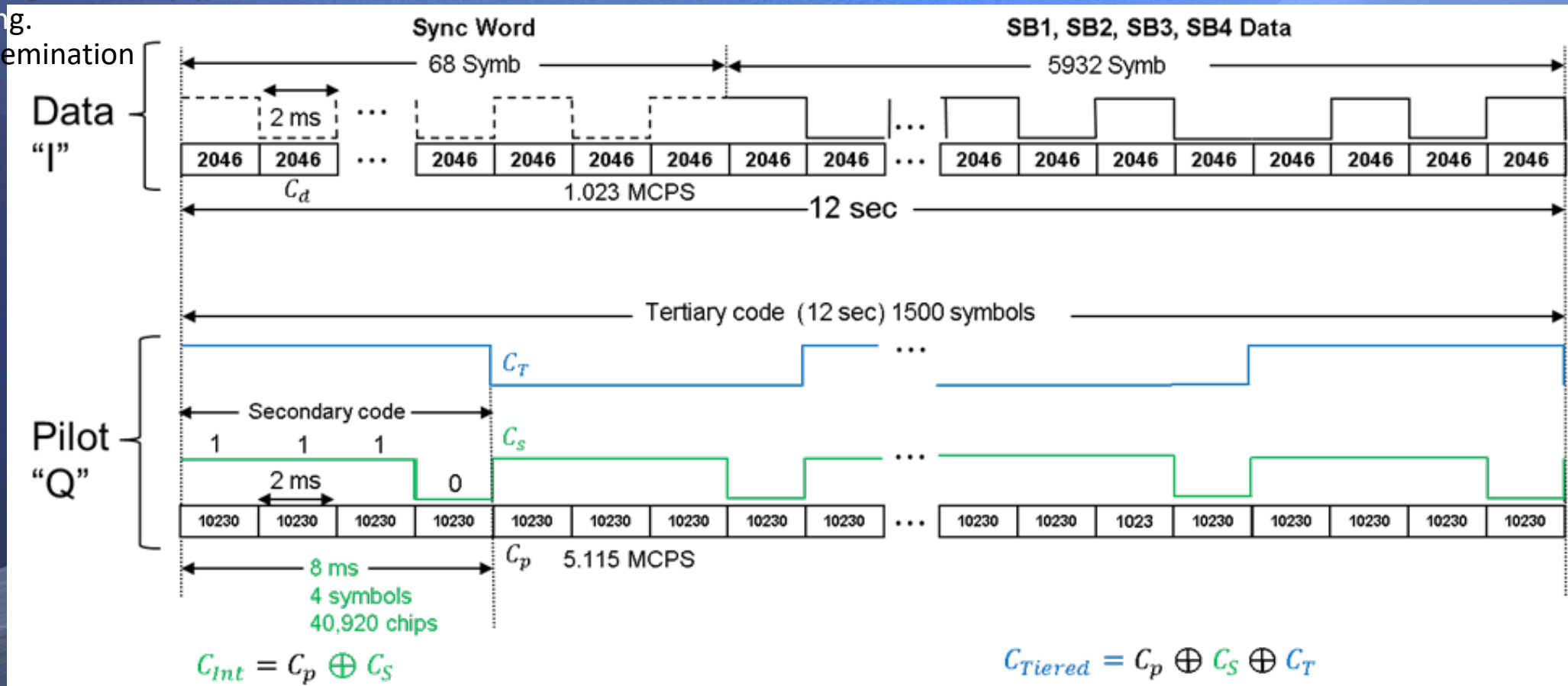
Two channels:

1) **Channel I [Data]** → BPSK(1), with PN code rate at 1.023 MHz

- a. Modulated with data symbols at 500 sps, supports frequent navigation data updates & other LunaNet data transmission needs;
- b. Frame synchronization pattern.
- c. SB1 includes Time of Interval (12 sec), Frame Identifier (FID), allowing future flexibility of data formatting

2) **Channel Q [Pilot]** → BPSK(5), with PN code rate at 5.115 MHz

- a. Precision tracking.
- b. Rapid Time Dissemination



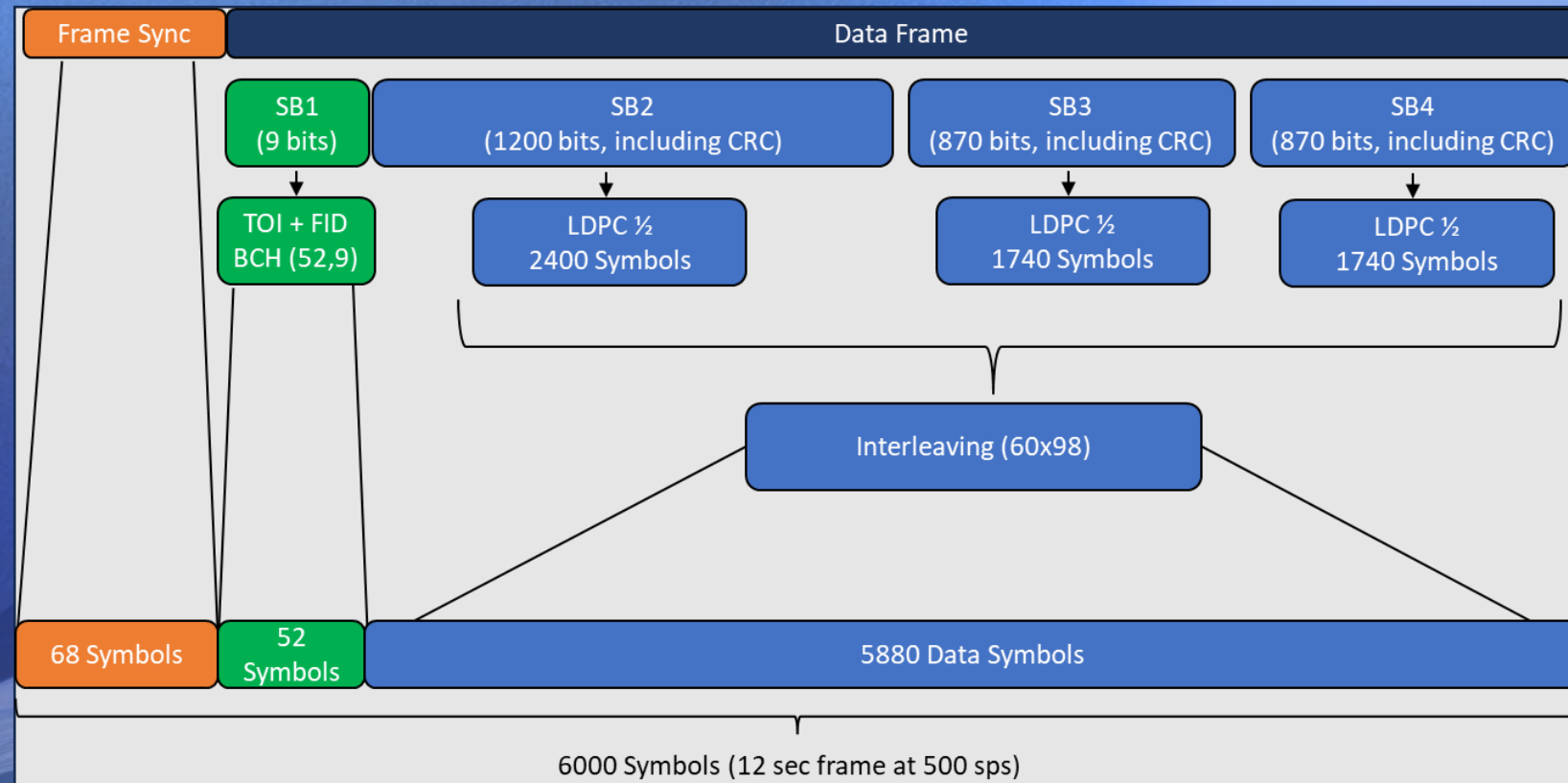
AFS Parameters (per AD-1 Vol A)



The AFS Data channel leveraged the L1C design with some significant differences:

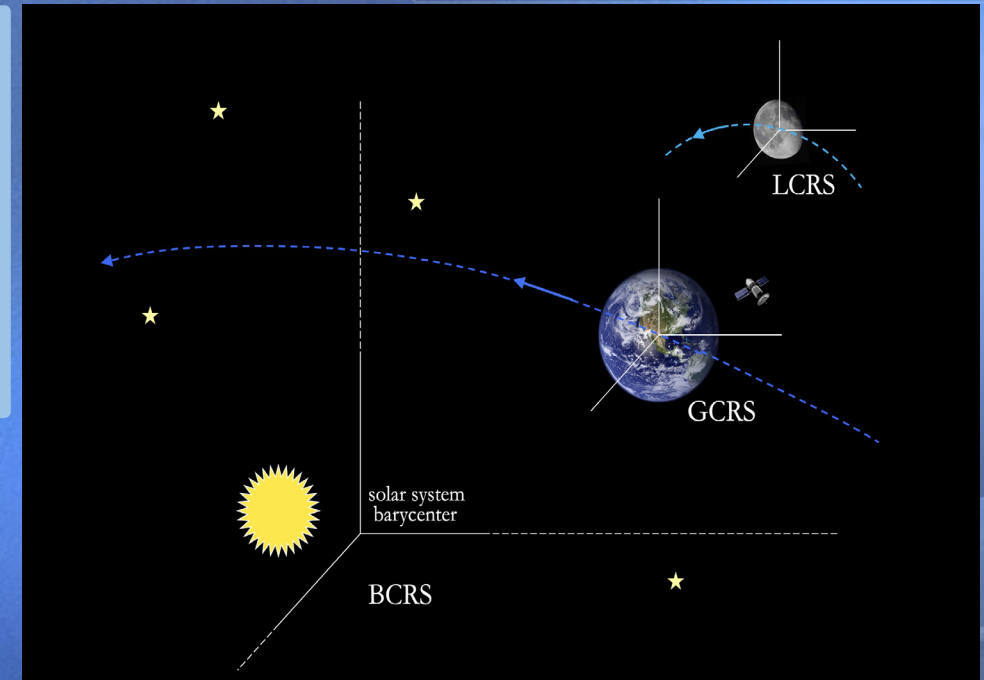
- BPSK(1) Modulation instead of BOC(1,1);
- 250 bits/sec instead of 50 bits/sec;
- 50 % Power is in the data channel instead of 25% as L1C;
- Sync word for low complexity receivers that do not acquire and track the pilot channel;
- LDPC decoding as described in the 5G NR standard.

Data Channel Frame Structure with Frame ID = 0



LunaNet Interoperability Specification AD-5: will define the interoperable parameters for reference systems and time that LunaNet-compliant services must meet.

LunaNet PNT relies on the international standards organizations, such as the International Astronomical Union (IAU), International Association of Geodesy (IAG), Bureau International des Poids et Mesures (BIPM), and International Telecommunications Union (ITU), to identify definitions of these critical underpinnings through international recognition and consensus.



More on this in Session 3 of this Workshop.

PNT Services rely on definition, adoption, and maintenance of common lunar geodetic and time systems, and transforms to other frames and UTC.

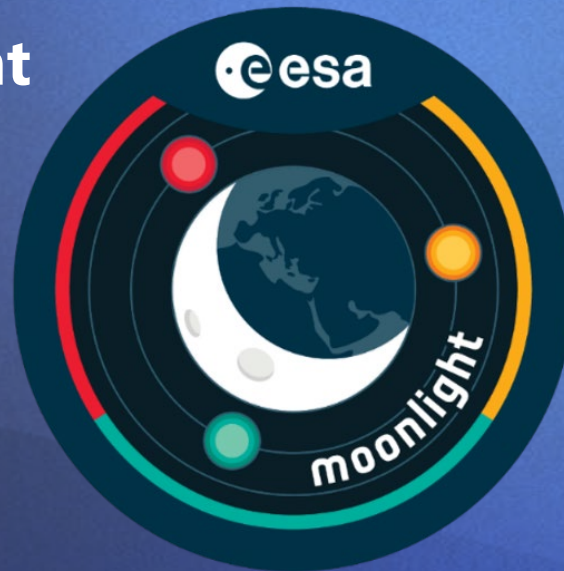
- The Interagency Operations Advisory Group initiated a Committee to Study LunaNet Governance.
- Recognizing that near-term coordination is needed, the three agencies participating in LunaNet will form the Coordinated LunaNet Administration Partners to handle items such as:
 - Allocation of specific identifiers to LNSP nodes
 - Reference orbits
 - Parameter/signal monitoring and validation

LunaNet Orbital PNT Service Providers



**ESA Moonlight
LCNS
(2028~)**

**Contractor:
Telespazio**



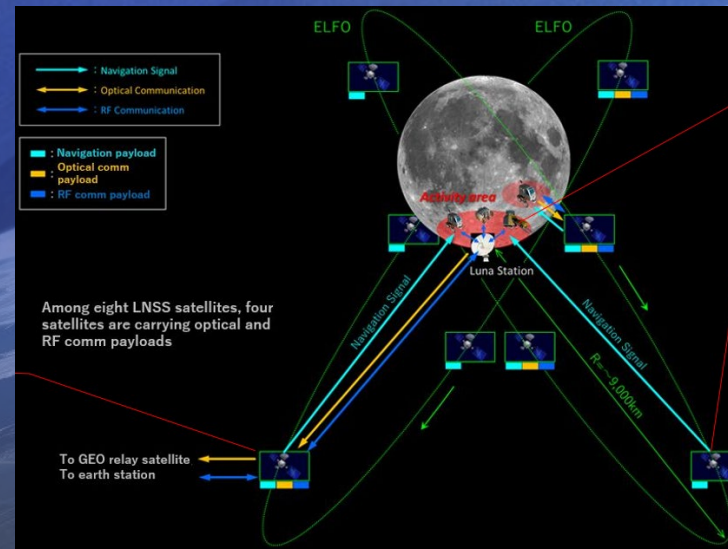
**NASA LCRNS
(2026~)**

**Contractor:
Intuitive
Machines**



**Japan LNSS
(2028/2029~)**

**ArkEdge Space
was recently
selected
✂PNT only**



**LCNS:
Lunar Communications and
Navigation Services**
**LCRNS:
Lunar Communications Relay
and Navigation Systems**
**LNSS:
Lunar Navigation Satellite System**

Concluding Summary



- LunaNet definition established currently via tri-lateral working groups to develop interoperability specifications that address communications, PNT, data services, security, and the foundational reference systems for these services in the lunar environment.
- LunaNet leverages international standards where applicable.
- The Augmented Forward Signal provides a broadcast signal for PNT, similar to terrestrial GNSS concept.
- Point-to-Point signals offer additional PNT capability, including delivery of messages for supplemental navigation/time products.
- NASA, ESA, and Japan instantiations of LunaNet systems are underway.

Questions?