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LUNAR COMMUNICATIONS RELAY AND NAVIGATION SYSTEMS

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Lunar Relay Services Requirements Document (SRD)

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Lunar Communications Relay and Navigation Systems (LCRNS) Lunar Relay Services Requirements Document (SRD)

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Preface

This is the NASA LCRNS Lunar Relay Service Requirements Document.

This document is controlled by the LCRNS Project Configuration Control Board (CCB). This document will be updated by Documentation Change Notice (DCN) or complete revision.

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Change History Log

Revision	Effective Date	Description of Changes (Reference the SCoRe Approval Date)
-	10/18/2022	Released by LCRNS-SCoRe-0056
A	11/04/2022	Released by LCRNS-SCoRE-0059
B	12/05/2022	Released by LCRNS-SCoRE-0062 Added communications polarization requirements for S- and Ka-Bands, and for AFS ubiquitous S-Band signal. Removed PRS5 from Table C-1 items 4.2, as Multiple Access Return functionality is not an IOC capability
DCN 001	03/22/2023	Update Table C-1 and LCRNS.3.0590

Table of TBDs/TBRs/TBSs

Action Item No.	Location	Summary	Individual/ Organization Actionee
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TBD-1	Table 3-4	S-Band Return Link Frequency (SAR)	
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TBD-4	Table 3-5	Symbol Rate Range - PFS 5	
TBD-5	Table 3-5	Symbol Rate Range - PRS 5	
TBR-1	Section 1, Paragraph 1	EOC starting year	
TBR-2	Table 3-1	Availability (Nominal/crit) IOC-A,B,C	
TBR-3	Table 3-2	Availability (Nominal/crit) EOC	
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TBR-5	LCRNS.3.0130	GDOP < 6	
TBR-6	LCRNS.3.0260	Decryption of user data for EOC	
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TBR-8	LCRNS.3.0310	SLP Earth fwd/rtn latency from user to NSN <3.0s	
TBR-9	Table 3-4	Proximity link - optical - fwd freq	
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TBR-15	LCRNS.3.0360	Freq bands are a subset of international standards	
TBR-16	LCRNS.3.0360	Optical comm only needed for EOC	
TBR-17	Table 3-7	Approximate Artemis data volume	
TBR-18	Table 3-9	Artemis data volume – fwd link	
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TBR-20	LCRNS.3.0470	Mission reference trajectories in Appendix B	
TBR-21	LCRNS.3.0530	Reliable delivery of bundles >= 95%	
TBR-22	LCRNS.3.0570	User PNT performance	
TBR-23	LCRNS.3.0630	LunarSAR detection within 5 minutes	
TBR-24	LCRNS.3.0630	LunarSAR compliant message 35 dBM EIRP	
TBR-25	LCRNS.3.0640	LunarSAR detection within 5 minutes	
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TBR-27	LCRNS.3.0660	LunarSAR relay messages within 5 minutes of beacon activation	
TBR-28	LCRNS.3.0670	Independent location of 95% within 10 minutes of activation	
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Section 1. Introduction

The NASA Lunar Communications Relay and Navigation Systems (LCRNS) Project has defined a set of requirements for Lunar Orbiting Relay *Services* by LunaNet Service Providers (LNSP) or Service Providers (SP) to support Artemis missions and assets (Human Landing System, Orion, Lunar Terrain Vehicle, Pressurize Rover, Extravehicular Activities, etc.), NASA payloads utilizing the Commercial Lunar Payload Services (CLPS) program, and other NASA science and technology missions in the lunar regime. The service is expected to initially include a few relays in lunar orbit matched to service provider ground stations in what is referred to as the Initial Operating Capability (IOC), covering the 2025 through 2028 timeframe. The IOC capability will be gradually built and validated over three increments during this timeframe, with full operational IOC capability in place by 2028. A more complex network will grow to meet expanding needs during the Enhanced Operating Capability (EOC), starting in 2030 (TBR) and beyond.

This LCRNS Services Requirements Document (SRD) covers LNSP communication and navigation services from users in the lunar proximity to a predefined NASA Near Space Network (NSN) interface point on Earth, and from Earth (via NSN interface point) to lunar users via space links. In addition, it covers services to lunar users communicating and navigating within the lunar proximity independent of Earth. Key interface performance requirements to lunar vehicles (i.e., HLS, LTV, CLPS, etc.) are included in this document. Relay service providers ground stations interface to the NSN network. The companion and applicable LunaNet Interoperability Specification, LNIS V.4 (ESC-LCRNS-SPEC-0015) provides a specific set of Interoperability Specifications (Appendix C) that must be met by all LNSP. It is expected this document will evolve as exploration and science element designs and concepts of operation mature.

1.1 Threshold Relay Capabilities by Increment (IOC)

IOC capabilities form the set of threshold requirements that shall be met by a LNSP. EOC capabilities can be implemented initially but are not part of the threshold set. Other NASA documentation may refer to the IOC capability as “sortie,” and the EOC capability as “Artemis Base Camp (ABC).”

IOC will be validated in three increments, based on Agency needs. Table 1-1 shows the capabilities needed for each mission and IOC increment assigned (A-Alpha, B-Bravo, and C-Charlie). Appendix A contains a SRD requirements effectivity spreadsheet based on mission capabilities needed per IOC increment for verification/validation. An effectivity listed as IOC means the requirement is applicable to *all* IOC increments.

At the end of each IOC increment, the provider will have a demonstrated capability that meets all the requirements mapped to that increment including any preceding one(s). This incremental verification/validation approach will allow capabilities to be well matched to the time periods by which they are required. The final validation increment (IOC-C) shall result in a system fully compliant with all LCRNS SRD IOC requirements.

Table 1-1 Artemis IOC Increment Capabilities

	IOC-Alpha	IOC-Bravo	IOC-Charlie
Effectivity	2025	2027	2028
Capabilities	-Communication support (one S-Band bidirectional link and one simultaneous Ka-Band return link) -RF and waveform compatibility with LNIS -AFS -NSN interface	-Enhanced communications support (one S-Band bidirectional link and one simultaneous Ka-Band bidirectional link) -RF and waveform compatibility with LNIS -Multiple AFS -NSN interface	-Full set LCRNS SRD IOC requirements upon completion

1.2 Document Conventions, Definitions, and Notations

This document uses the term *service* for all exchange of data with the user mission platform, as well as information derived from the data exchange and radio signals received (e.g., for Position, Navigation, and Timing (PNT) services). This term is inclusive of all transmit, receive, radiometric, science, messaging, and calibration services. The terms LNSP shall refer to the provider network executing said service. Except for radiometric tracking, the lunar relay does not perform telemetry and command processing functions for the purpose of controlling users, it only provides a data pass-through. *Data rates are given as the bit rate after framing*. Any additional rate capability needed to accommodate encoding or modulation must be accounted for.

In this document, the terms of *forward* and *return* in lunar proximity are defined from a relay-centric perspective. A signal originating from a lunar user and being sent to the relay service is a *return* signal. A signal originating from the relay service and being sent to a lunar user is a *forward* signal. In addition, *Direct-to-Earth* or DTE refers to the geometric line-of-sight visibility of relays or users in the lunar vicinity, and not to a directional ("to") reference. Hence, DTE communications can refer to a transmission originating from the lunar vicinity, as well as a transmission originating from Earth. Directionality is qualified by the *forward* or *return* link nomenclature. Hence for a transmission originating on Earth, a *forward DTE* link can be established with a user in lunar space. *Proximity* links are used to refer to user-relay, or user-user links in the lunar vicinity, whether forward or return. Finally, *cross-links* are used for communications between relays.

A requirement is preceded by a *shall*. This document follows the formatting style of the document template defined by the SCaN Program Configuration Management Office. In some cases, the values of quantities included in this document are not certain and are designated as *to be reviewed* (TBR), *to be determined* (TBD), or *to be supplied* (TBS). Where approximate values of such quantities are known and provide useful guides for development, these are shown along with the TBR notation. Where no value is yet known, a TBD is included. Where a value is known but has not been supplied to the SRD book manager, a TBS is included.

1.2.1 Coverage

A service *covers* a particular volume of space *if the system can close the link* with a specified number of users in that volume. That assumes knowledge of user receiver performance, how many users must be serviced simultaneously, and how long is the service expected to last. Coverage to be measured over one earth month.

1.2.2 Availability

Availability is a subordinate of coverage, in the sense that no service can be made available if coverage does not exist. Availability in this document is defined as follow:

Availability = $(T_{expected} - T_{down})/T_{expected}$

Where: $T_{expected}$ is the time that a service is expected to be operational to meet coverage requirements and T_{down} is the time that the service is not operational. Examples of down time include software deliveries, engineering changes, system failures, system maintenance, slew times, and internal tests not requested by customer missions. The amount of time considered in the availability calculation shall be the time customers are prevented from scheduling the service averaged over one earth month.

1.2.2.1 Operational Service Availability

For a service provider availability is measured between the point when a relay receives the user signal to the NSN designated interface point. This is the only link path the service provider controls. For end-to-end availability the NSN interface and/or terrestrial communications systems will need to be added and is not covered in this SRD.

1.2.3 Service Volume

Service volume identifies the *minimum* space volume where coverage, as defined in this document, shall be met. There are three service volumes identified in this document.

Service Volume I (SV1): Includes lunar surface areas below -80 degrees south latitude and up to an altitude of 125 kilometers. Rationale: The intent of SV1 is to support initial services to surface missions and users in low lunar orbit or in transit to/from the surface, when within the service volume.

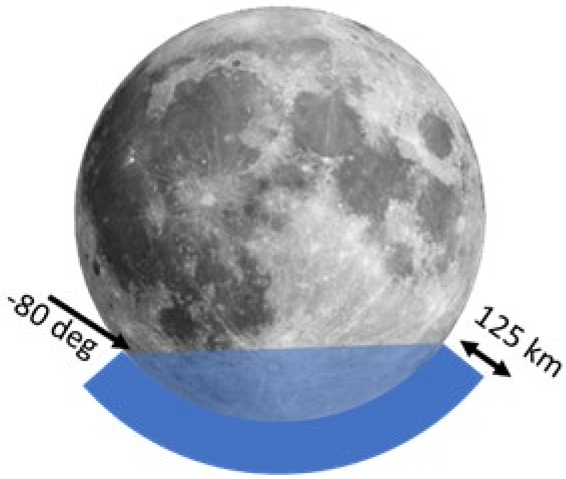

Figure 1-1 Service Volume I (SV1)

Service Volume II (SV2): Includes lunar surface areas below -75 degrees south latitude and up to an altitude of 200 kilometers. Rationale: The intent of SV2 is to support surface missions as well as users in low lunar orbit or in transit to/from the surface.

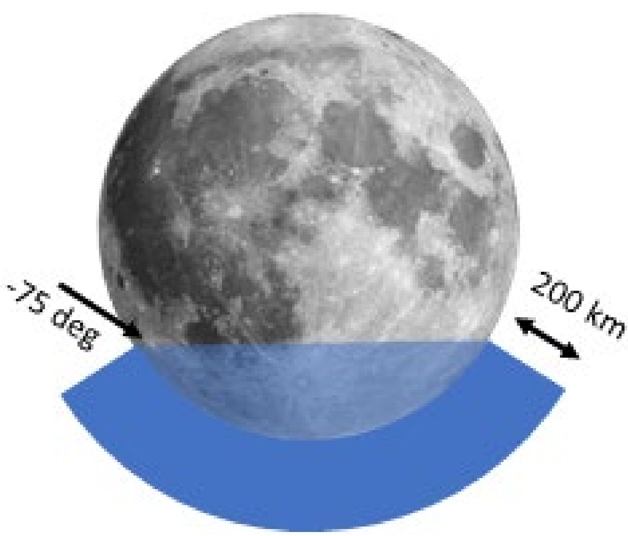

Figure 1-2 Service Volume II (SV2)

Service Volume III (SV3): Includes lunar surface areas for all latitudes and altitudes up to a minimum of 200 kilometers for full global coverage of the moon. Rationale: The intent of SV3 is to provide global coverage to remove mission placement constraints, supporting surface missions as well as users in low lunar orbit or in transit to/from the surface.

Figure 1-3 Service Volume III (SV3)

1.2.4 Service Provider Latency

Service Provider Latency is defined as the amount of time (measured in seconds) between a signal leaving a mission User transmitter antenna to the time it is delivered to the NSN interface or to the satellite mission's data processing system/control center, whichever is specified in the Mission Data Workbook. For purposes of this document, latency is measured only to the NSN interface.

1.2.5 Nominal Services

Normal Services cover typical and regular mission User activities such as telemetry, voice, video, and command and science/payload data.

1.2.6 Critical Services

Critical Services include communication and navigation services that must always provide reliable and secure services without degradation of performance. Any function or group of functions is deemed mission critical if its failure will result in a situation whereby the User spacecraft cannot be recovered. Examples of Critical Services include Launch, early orbit ops, human spaceflight, descent, crewed lunar surface operations, and spacecraft contingency. Critical services encompass both Contingency and Emergency activities. Contingency activities will occur when the user mission platform experiences a failure or degradation in function or performance that affects normal data collection, or otherwise compromises the health and safety of the system. Anomalies could be sudden, discrete events, such as the failure of a critical component, or could be a gradual degradation in performance detected by engineering trending that permits action prior to the occurrence of a mission-threatening situation. Contingency Services include all the activities performed during Normal Services, plus additional items such as configuration management, and other troubleshooting services as needed. Emergency activities are a response to an unexpected anomaly that if not responded to in a timely manner would result in loss of mission, or in the case of Humans Spaceflight activities, Loss of life. Emergency service requests will be coordinated by the NSN Project directly with the LNSP to receive immediate communications services to prevent loss of their user mission platform, enable safing, restore normal operations, and preserve life.

1.2.7 Data Services

Data services or operations is defined as the network routing and processing of information associated with both real-time and store-and-forward (i.e., delay/disruption tolerant networking) capabilities between a user in lunar space and the NSN demarcation point (and vice versa). It differs from the simple "communications" reference which is traditionally employed generically.

1.2.8 PNT Terminology (AFS/Point-to-Point/LANS)

PNT services enable missions to determine position, velocity, surface location, plan trajectories, execute maneuvers, and maintain accurate time in a timeliness sufficient to meet mission requirements. PNT services can be offered via a combination of standardized signals for Doppler, ranging, timing, and standard messages and protocols for the exchange of measurements and products. These are needed for safety, situational awareness, communication, and mission and science objectives.

To offer these services and provide interoperability, the intent is to take maximum advantage of the communications links through judicious signal structure definitions. This can be accomplished in several ways. One method is to provide PNT through dedicated Point-to-Point (P2P) communications links with a user. However, there is a need for lunar-global provisioning of PNT services to provide adequate geometry and appropriate time-to-first-fix to meet user requirements. Thus, a second method using an Augmented Forward Signal (AFS) provides PNT functionality independent of dedicated user communications links to enable multiple user reception of the signal simultaneously. Through the build-up of LCRNS nodes, this will establish a Lunar Augmented Navigation System (LANS). Figure 1-4 diagrams these PNT service options.

1.2.8.1 Point-to-Point (P2P)

These services are expected to be provided by scheduled direct links between the user and the provider. A point-to-point link can provide a reference signal for PNT observables with the associated messages. Alternatively, a signal that is not inherently designed to offer PNT observables may still be employed to transmit messages that support PNT.

1.2.8.2 Augmented Forward Signal (AFS)

The AFS is a special case instantiation of the reference signals structured to present the user with the ability to measure pseudorange, Doppler, and Time Transfer coupled with relevant information in messages. The compatible LCRNS nodes will transmit the AFS, as described in ESC-LCRNS-SPEC-0015. A collection of nodes transmitting the AFS constitutes the Lunar Augmented Navigation Service (LANS).

1.2.8.3 Lunar Augmented Navigation Service (LANS)

The LANS via AFS is a multiple access forward link and allows reception by multiple users from the same LCRNS node (one-to-many). Additionally, it also supports a many-to-one concept (i.e., GNSS-like with AFS signals from multiple LCRNS nodes received by one user) owing to the mandatory time synchronization of the nodes, the coordinated generation of PNT-specific navigation messages, and the Code Division Multiple Access (CDMA) differentiation among the LCRNS nodes.

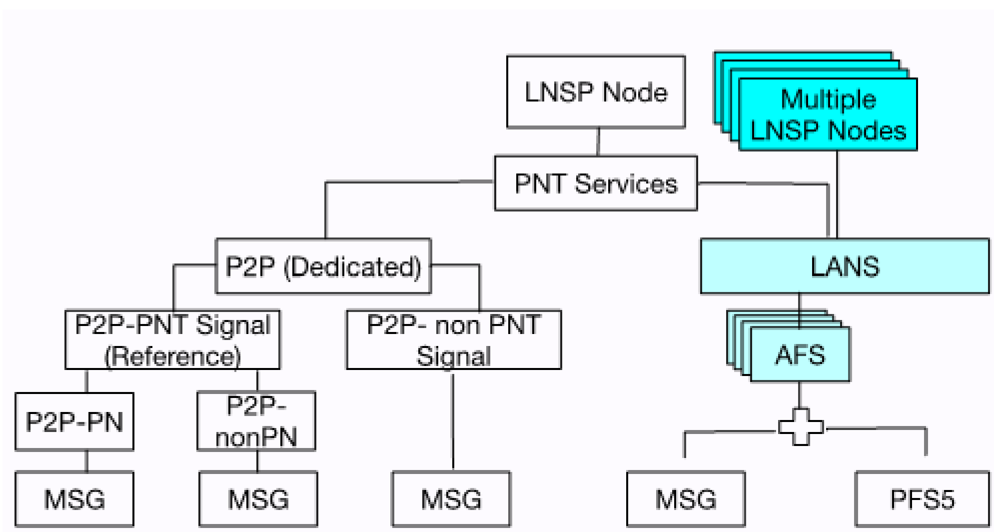

Figure 1-4 LCRNS PNT Services

1.2.9 Configuration Control

Changes to this requirements document shall be controlled using procedures set forth in the NASA LCRNS Configuration Control Board documentation.

Section 2. Documentation

2.1 Applicable Documents

The following documents form a part of this SRD to the extent specified herein. In the event of conflict between documents referenced and the detailed contents of this document, the requirements specified herein shall govern.

Table 2-1 Applicable Documents

Document No.	Document Title
ESC-LCRNS-SPEC-0015	LunaNet Interoperability Specification (LNIS) Document, Version 4

With few exceptions, SCaN considers only adopted standards (such as Consultative Committee for Space Data Systems -CCSDS- blue books) as applicable.

2.2 Reference Documents

The following documents listed here were used as a reference material for this document.

Table 2-2 Reference Documents

Document No.	Document Title
HEOMD-003-02	International Communication System Interoperability Standard (ICSIS), Revision B Draft – June 2022.
SCaN-SRD Revision 6	SCaN Requirements Document Revision 6
NASA-STD-1006	Space System Protection Requirements
ESC-NSN-ICD-0143	Near Space Network (NSN) NexTEra to Space Link Provider (SLP) Interface Requirements Document (IRD), August 2022

Section 3. Lunar Relay Service Requirements

3.1 Lunar Relay Service Functional Requirements

LCRNS.3.0010 Interoperability and Compatibility
The Lunar Relay service shall comply with the interfaces specified in the LunaNet Interoperability Specification LNIS V.4 (ESC-LCRNS-SPEC-0015) per the compliance matrix in Appendix C.
Rationale: Lunar relay nodes function within the LunaNet architecture, which specifies a set of standard interfaces enabling interoperability and compatibility between systems including operation between lunar and earth elements that contribute to the network. Appendix C provides the compliance matrix for the subset of requirements within this specification for each phase/increment of missions. This requirement ensures that the Lunar Relay Service interfaces with Lunar User Systems and provide communication and PNT services within an interoperable framework. The primary goal of LCRNS for Artemis is to enable communication and PNT services between the crew and mobility assets on the lunar surface and the Earth. Artemis elements will be able to use lunar relay, Gateway or other assets interchangeably depending on specific needs.
Effectivity: IOC, EOC

LCRNS.3.0020 Lunar Relay Communications Function
The Lunar Relay Service shall provide key operational support to lunar systems.
Rationale: Providing key operational support implies the existence of a robust design, including failure tolerance or functional redundancies as well as high-quality design standards. Lunar systems include HLS, LTV, Pressurized Rover, Habitat, ISRU, Robotic Systems.
Effectivity: IOC, EOC

LCRNS.3.0030 Lunar Relay Ubiquitous Signal for Position, Navigation, and Timing and Broadcast Messaging Service
The Lunar Relay service shall provide Augmented Forward Signals (AFS) with broadcast messaging.
Rationale: This signal will enable users' in-situ autonomous lunar orbiting and surface asset navigation, time knowledge, and situational awareness to meet their mission requirements. Crewed, uncrewed, and robotic assets in the lunar space volume region and on the lunar surface need to navigate and have lunar-centric situational awareness independent of Earth-assets (e.g., DSN, NSN, Commercial Stations). The lunar relay provision of signals structured to provide pseudorange, Doppler, and time transfer, with associated message content, enables a lunar-relative and inertially-tied navigation/positioning/time solution to meet their operational requirements for PNT knowledge, network knowledge, and alerts. Drivers for PNT accuracy and timeliness include HLS landing accuracy, and

surface human and robotic mobility asset(s) position knowledge, sampling, ISRU for science-related needs and geographic location, and utilization payload positioning.
Effectivity: IOC, EOC

LCRNS.3.0040 Lunar Relay Position, Navigation, and Timing Function
The Lunar Relay service shall provide functionality via dedicated service for in-situ autonomous lunar orbiting and surface asset navigation and time knowledge.
Rationale: Users unable to benefit from the functionality described in LCRNS.3.0030, require PNT services provided via dedicated links. Crewed, uncrewed, and robotic assets in the lunar space volume region and on the lunar surface need to navigate independent of Earth-assets (e.g., DSN, NSN). The lunar relay provision of signals structured to provide pseudorange, Doppler, and time transfer, with associated message content, enables a lunar-relative and inertially-tied navigation / positioning / time solution to meet their operational requirements. Drivers for PNT accuracy and timeliness include HLS landing accuracy, and surface human and robotic mobility asset(s) position knowledge, ISRU for science-related needs and geographic location, and utilization payload positioning as listed in section 3.2.3.
Effectivity: IOC, EOC

LCRNS.3.0050 Lunar Relay Real-time Data Service Functionality
The Lunar Relay Service shall provide a lunar communications relay capable of real-time data relay services between Earth and Lunar Users.
Rationale: The lunar communications network is a critical piece to enable mission execution during all mission phases. This requirement defines the capability required to support the initial crewed missions to the lunar surface. Realtime is defined as data flow through the relay with the minimum latency achievable. This service requires all links between the sender and the receiver to be available.
Effectivity: IOC, EOC

LCRNS.3.0060 Lunar Relay Non-Real-Time Data Service Functionality
The Lunar Relay Service shall provide a lunar communications relay capable of store-and-forward data relay services between Earth and Lunar Users.
Rationale: A store-and-forward capability is needed to increase the amount of data that the network can return to Earth and for example, allows coverage of far-side assets when orbital mechanics preclude direct contact with Earth
Effectivity: IOC-C, EOC

LCRNS.3.0070 Relay between Lunar Users (Real-Time Data Service)
The Lunar Relay Service shall provide a lunar communications relay capable of real-time data relay services between Lunar Users.
Rationale: Communication and commanding between lunar platforms without routing to Earth will be necessary to execute a sustained lunar presence
Effectivity: EOC

LCRNS.3.0080 Relay between Lunar Users (Non-Real-Time Data Service)
The Lunar Relay service shall provide a lunar communications relay capable of store-and-forward data relay services between Lunar Users.
Rationale: Communication and commanding between lunar platforms without routing to Earth will be necessary to execute a sustained lunar presence.
Effectivity: EOC

LCRNS.3.0090 Operational Service Availability (nominal IOC)
The Lunar Relay Service shall provide nominal operational service Availability as shown in Table 3-1 for each of the IOC increments, averaged over a period of one Earth month.
Rationale: Operational service availability will increase over the IOC steps as the LCRNS relay constellation builds up, to eventually meet the final IOC figure.
Effectivity: IOC step per table 3-1

LCRNS.3.0091 Operational Service Availability (critical IOC)
The Lunar Relay Service shall provide critical operational service Availability as shown in Table 3-1 for each of the IOC increments, averaged over a period of one Earth month.
Rationale: Operational service availability will increase over the IOC period as the LCRNS relay constellation builds up, to eventually meet the final IOC figure.
Effectivity: IOC step per table 3-1

Table 3-1 Operational Service Availability (IOC Increments)

Support	IOC A	IOC B	IOC C
Nominal	75% (TBR)	85% (TBR)	95% (TBR)
Critical	N/A	85% (TBR)	98% (TBR)

LCRNS.3.0092 Operational Service Availability (nominal EOC)
The Lunar Relay Service shall provide nominal operational service Availability as shown in Table 3-2 for EOC, averaged over a period of one Earth month.
Rationale: Operational service availability in EOC is consistent with current NSN network performance for LEO and DTE users.
Effectivity: EOC

LCRNS.3.0093 Operational Service Availability (critical EOC)
The Lunar Relay Service shall provide critical event operational service Availability per Table 3-2 for EOC, averaged over a period of one Earth month.
Rationale: Operational service availability in EOC is consistent with current NSN network performance for LEO and DTE users.
Effectivity: EOC

Table 3-2 Operational Service Availability (EOC Increment)

Support	EOC
Nominal	98% (TBR)
Critical	99.5% (TBR)

LCRNS.3.0095 Simultaneous Service to Multiple Users (Real Time)

The Lunar Relay Service shall provide simultaneous services as shown in Table 3-3 for each IOC increment and EOC. All Ka-band, S-band, and AFS services shown for a given increment/phase are simultaneous to each other.

Rationale: The Lunar Relay Service must be able to support an increasing number of NASA users. It is expected that these users will require both S-band and Ka-band services. Both communications and navigation services must be scaled up to full IOC (IOC-C) and EOC capability per Table 3-3. In the case of one pair of simultaneous S-Band and Ka-Band services for instance, this will allow monitoring of spacecraft telemetry for one user in S-Band, while providing a high-rate link for video transmissions to another in Ka-Band. For Artemis assets on the surface in IOC, it may be assumed that both users are within close proximity (20 km) to one another.

Effectivity: Per Table 3-3

Table 3-3 Minimum Constellation Sizing Requirements

	IOC-Alpha			IOC-Bravo				IOC-Charlie			EOC		
Service Type	Ka-band	S-band	AFS	Ka-band	S-band	AFS		Ka-band	S-band	AFS / LANS	Ka-band	S-band	AFS / LANS
Number of simultaneous links	1	1	1	1	1	2	3	2	2	4	2	2	5
Forward/ Return Link	R only	F+R	F only	F+R	F+R	F only	F only	F+R	F+R	F only	F+R	F+R	F only
Service Volume	SV1			SV1				SV2			SV3		SV3
Min. % Coverage of an Earth Day	70% TBR			75%	90%	70%	40%	75%	90%	40% (with max. spatial GDOP<6)	75%	95%	99%

Notes:
-Links from AFS need to provide geometric diversity; LANS is defined by a minimum of four links in view simultaneously from geometrically diverse relays.
-Per requirement LCRNS.3.0030, links for AFS will be ubiquitous for each relay.
-Minimum percent coverage of an Earth Day throughout an active Artemis campaign.

LCRNS.3.0096 Service Volume (Phasing)

The Lunar Relay Service shall provide services within the Service Volumes shown in Table 3-3 for each of the IOC and EOC Intervals/Phases.

Rationale: "Service Volumes" define the minimum space volume to be serviced by SPs.

Effectivity: IOC, EOC Per Table 3-3

LCRNS.3.0097 Service Coverage (Phasing)
The Lunar Relay Service shall provide coverage within the minimum Service Volumes as shown in Table 3-3 for each of the IOC increments and EOC.
Rationale: Coverage requirements vary per service type and are expected to change both depending on number of users and operational criticality.
Effectivity: IOC, EOC Per Table 3-3

LCRNS.3.0100 Ka-Band Return Data Services Relay Network Coverage
The Lunar Relay Service shall provide dedicated Ka-band return data services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: The high-rate data service requires Ka-links.
Effectivity: IOC, EOC Per Table 3-3

LCRNS.3.0105 Ka-Band Forward Data Services Relay Network Coverage
The Lunar Relay Service shall provide dedicated Ka-band forward data services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: The high-rate data service requires Ka-band links.
Effectivity: IOC-B, IOC-C, EOC Per Table 3-3

LCRNS.3.0110 S-Band Return Data Services Relay Network Coverage
The Lunar Relay Service shall provide dedicated S-band return data services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: Health and status and PNT services can be met with more available and mature S-band systems. Availability of these services can be increased without undue burden on the development effort.
Effectivity: IOC, EOC Per Table 3-3

LCRNS.3.0113 S-Band Forward Data Services Relay Network Coverage
The Lunar Relay Service shall provide dedicated S-band forward coverage to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: Health and status and PNT services can be met with more available and mature S-band systems. Availability of these services can be increased without undue burden on the development effort.
Effectivity: IOC, EOC Per Table 3-3

LCRNS.3.0115 Point-to-Point PNT Services Relay Network Coverage
The Lunar Relay Service shall provide Point-to-Point link PNT services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: PNT coverage is needed for Artemis vehicle autonomy in lunar space for the S-band and Ka-band dedicated links.
Effectivity: IOC, EOC Per Table 3-3

LCRNS.3.0120 Lunar Augmented Navigation System (LANS) Service
The Lunar Relay Service shall provide Lunar Augmented Navigation System (LANS) services within the Service Volumes shown in Table 3-3.
Rationale: Availability of the LANS service will be targeted to support IOC-C missions, with full lunar coverage attained in EOC. The LANS consists of multiple AFS signals and associated messages. Table 3-3 represents values for four signals in view to create the necessary geometric diversity.
Effectivity: IOC-C, EOC Per Table 3-3

LCRNS.3.0130 LANS Service Geometric Dilution of Precision (GDOP)
The Lunar Relay Service shall provide LANS services with Geometric Dilution of Precision (GDOP) <6 (TBR) in the Service Volumes identified in Table 3-3.
Rationale: GDOP is fundamental in achieving performance, in terms of knowledge and timeliness to meet user needs.
Effectivity: IOC-C, EOC

LCRNS.3.0140 Lunar Service Situational Awareness
The Lunar Relay Service shall share relay ephemeris data with other providers.
Rationale: NASA seeks an interoperable network with national and international participants. The ability to share accurate relay information with respect to their orbital ephemerides enables a true navigation network, prevents collisions, and allows scheduling of assets without ground intervention. In IOC ephemeris sharing can be done indirectly through an Earth facility.
Effectivity: IOC, EOC

LCRNS.3.0150 Time Synchronization
The Lunar Relay Service shall synchronize time with an external common reference timing source shared with other providers.
Rationale: NASA seeks an interoperable network, per the LunaNet Interoperability Specification, with national and international participants. The ability to share accurate relay information with respect to their time knowledge and residual delay in a common time system and orbital ephemerides enables a true navigation network, prevents collisions, and allows scheduling of assets without ground intervention. A common reference time system will be defined within the LNIS.
Effectivity: IOC, EOC

LCRNS.3.0160 Provider to Provider Message Exchange
The Lunar Relay Service shall support messaging services between different providers, enabling exchange of navigation, schedule and space situational awareness information.
Rationale: NASA seeks an interoperable network with national and international participants. The ability to share relay information with respect to their orbital ephemerides and other attributes enables a true synchronized navigation and communication network, prevents collisions, and allows scheduling of assets without ground intervention.
Effectivity: EOC

LCRNS.3.0170 Dynamic Phases
The Lunar Relay Service shall cover dynamic events such as lunar vehicle descent and ascent, lunar orbiting vehicles, and mobility surface vehicles and personnel.
Rationale: The dynamic environment of lunar systems will require sufficient coverage to support precise navigation, DTE communications blockage, and search and rescue operations. Descent to the lunar surface includes landing; ascent includes lift-off from the lunar surface. It is recognized that during highly dynamic events, some signal services may be degraded or not possible due to the challenges of Doppler tracking. If a service requirement is not met during highly dynamic events, that should be clearly stated and explained. Reference trajectories are provided in this SRD Appendices.
Effectivity: IOC, EOC

LCRNS.3.0180 Dynamic Coverage– Low Lunar Orbit (LLO)
The Lunar Relay service shall provide communications and PNT services to crewed and robotic vehicles in a low lunar orbit (LLO) within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: The relay must be able to provide service while tracking user spacecraft in motion relative to the lunar surface.
Effectivity: Per Table 3-3

LCRNS.3.0190 Dynamic Coverage – Descent (IOC)
The Lunar Relay Service shall provide communications and PNT services to crewed and robotic vehicles while descending to the lunar surface from LLO within the applicable service volume and at the percent coverage shown in Table 3-3.
Rationale: The LCRNS Relay must be able to provide service while tracking user spacecraft in motion relative to the lunar surface. Descent to the lunar surface includes landing.
Effectivity: IOC per Table 3-3

LCRNS.3.0195 Dynamic Coverage – Descent (EOC)
The Lunar Relay Service shall provide continuous communications and PNT services to crewed vehicles while descending to the lunar surface from LLO within SV3 (Table 3-3).
Rationale: The LCRNS Relay must be able to provide service while tracking user spacecraft in motion relative to the lunar surface. Descent to the lunar surface includes landing.
Effectivity: EOC per Table 3-3

LCRNS.3.0200 Dynamic Coverage – Ascent (IOC)
The Lunar Relay Service shall provide communications and PNT services to crewed and robotic vehicles while in ascent from the lunar surface to LLO within the applicable service volume and at the percent coverage levels shown in Table 3-3.
Rationale: The LCRNS Relay must be able to provide service while tracking user spacecraft in motion relative to the lunar surface. Ascent includes lift-off from the lunar surface.
Effectivity: IOC per Table 3-3

LCRNS.3.0205 Dynamic Coverage – Ascent (EOC)
The Lunar Relay Service shall provide *continuous* communications and PNT services to crewed vehicles while in ascent from the lunar surface to LLO within SV3 (Table 3-3).
Rationale: The LCRNS Relay must be able to provide service while tracking user spacecraft in motion relative to the lunar surface. Ascent includes lift-off from the lunar surface.
Effectivity: EOC per Table 3-3

LCRNS.3.0210 Surface User Operations Coverage (generic)
The Lunar Relay Service shall provide communications and PNT services to users while on the lunar surface within the applicable service volumes shown in Table 3-3.
Rationale: The LCRNS Relay must be able to provide service on the lunar surface to human and robotic vehicles.
Effectivity: IOC, EOC per Table 3-3

LCRNS.3.0220 Crewed Surface Operations
The Lunar Relay Service shall provide communications and PNT services to crewed surface vehicle users within the applicable service volumes shown in Table 3-3.
Rationale: LTV, Unpressurized Rover, Pressurized Rover, and other Artemis mobility vehicle users while out of line of sight of the crewed lander will rely on lunar relay services for communication and PNT coverage in the service volumes shown in Table 3-3.
Effectivity: IOC, EOC per Table 3-3

LCRNS.3.0230 EVA surface extended Operations Duration
The Lunar Relay Service shall provide navigation services such that the NASA human spaceflight architecture on the lunar surface can meet a minimum of 24 hours of cumulative surface EVA time per crewmember per 7 Earth-day period during surface stays greater than or equal to 14 Earth-days.
Rationale: The primary goal of Lunar Relay is to enable communication between mobility assets on the lunar surface locally and with the Earth. EVA mobility elements will be able to use Lunar Relay Services for specific operational needs.
Effectivity: EOC

LCRNS.3.0240 EVA surface initial Operations Duration
The Lunar Relay Service shall provide PNT services so that the initial Artemis systems can be capable of supporting at least two lunar surface extra-vehicular activities (EVA), each lasting at least 4 hours nominally plus 1 hour contingency.
Rationale: The lunar relay service needs to cover the entirety of EVA operations as relayed through the HLS lander (IOC). This will both cover instances where DTE is not available and provides a backup to DTE if it is available.
Effectivity: IOC-C, EOC

LCRNS.3.0260 User Data Security
The Lunar Relay Service shall maintain user provided encryption sent to and from the lunar relays and Earth ground stations.
Rationale: Lunar relays will maintain user data encryption as it moves to and from endpoints – no decryption of user data through the relay path will be provided (TBR for EOC capabilities).
Effectivity: IOC, EOC

LCRNS.3.0270 Earth Independent Services
The Lunar Relay Service shall provide services between endpoints in the lunar vicinity without routing data to and from Earth.
Rationale: Routing data to and from Earth increases Earth-station usage, raises latency, and reduces throughput, versus routing data entirely in the lunar domain.
Effectivity: EOC

LCRNS.3.0280 Service Provider Real-time Data Latency
The Lunar Relay Service node shall limit the time between receiving real-time data and transmitting that data to the NSN interface point to less than 1.0 (TBR) seconds.
Rationale: Each relay node must limit on board processing of real-time data (voice, video, telemetry) to the minimum needed so as not to be disruptive to end-user operation. The current estimate is 5 seconds end-to-end from users on earth to users on the lunar surface. Each Service provider node is allocated 1.0 second. Does not include light time delays nor the NSN latency beyond the NSN interface point. This is not an end-to-end network latency measurement.
Effectivity: IOC, EOC

LCRNS.3.0310 Service Provider Earth Forward or Return Latency
The Lunar Relay Service shall limit the time between receiving/transmitting real-time data from a user to and from the NSN interface point to less than 3.0 (TBR) seconds each way.
Rationale: Command data is related to the real-time health and safety of the user mission platform and must be delivered to the mission platform quickly. Note this is not an end-to-end network latency measurement.
Effectivity: IOC, EOC

LCRNS.3.0320 Concurrency of Operations
The Lunar Relay Service shall provide concurrent operations of relay services for lunar communications, data operations, PNT services, and LunaNet messaging services.
Rationale: The lunar relay service needs to provide concurrent communications, real-time, store and forward data (no later than IOC-C), PNT, and messaging services with one or more lunar users while maintaining high data rate and low latency operations. Concurrent services are listed in Table 3-3.
Effectivity: IOC, EOC

LCRNS.3.0340 Ground Station (commercial or government) Interface to the NSN
The Lunar Relay Service shall interface with the NSN at the NSN demarcation point in the Cloud.
Rationale: An interoperable network will need a way to deconflict data services to/from users on Earth and in lunar space. The NSN provides a central hub where multiple providers are deconflicted and appropriate services selected. Assumes service provider has a mission operations center to manage and control the relay service nodes and includes the information necessary for its own flight operations.
Effectivity: IOC, EOC

LCRNS.3.0350 Quality of Service (QOS) metrics
The Lunar Relay Service shall provide real-time status and Quality of Service (QOS) metrics to the NSN.
Rationale: The overall system (relays, ground segment, users) must have the ability to monitor its own status and provide key performance metrics that prove it satisfies end-user needs. Relay/MOC should be able to determine that the relay is meeting its QOS metrics on a periodic basis based on telemetry received and trended each month. Metrics likely to be required are latency, availability, and data completeness.
Effectivity: IOC, EOC

3.2 Service Performance Requirements

3.2.1 Communications Requirements

LCRNS.3.0360 Lunar Relay Frequency Band Requirements
The Lunar Relay Service shall provide the frequency band services per Table 3-4.
Rationale: These bands are consistent with LNIS V.4 and represent a subset of approved international standards (TBR) for lunar communications and navigation. Optical communications (TBR), Multiple Access Return, and Search and Rescue are EOC capabilities.
Effectivity: IOC, EOC

Table 3-4 Lunar Relay Frequency Band Requirements

Link	Band	Forward Link Frequency	Return Link Frequency
Lunar Relay to/from Lunar System (Proximity Link)	S-Band	2025 - 2110 MHz	2200 - 2290 MHz
	Ka-Band	23.15 - 23.55 GHz	27.0 - 27.5 GHz
	Optical	1530 nm (TBR)	1565 nm (TBR)
Lunar Relay to/from Lunar Relay (Crosslink)	Ka-band	23.15 - 23.55 GHz	27.0 - 27.5 GHz
	Optical	1550 nm (TBR)	1550 nm (TBR)
Earth to/from Lunar Relay (Direct-to-Earth Link)	X-Band	7190 - 7235 MHz	8450 - 8500 MHz
	Ka-Band	22.55 - 23.15 GHz	25.5 - 27.0 GHz
	Optical	1530 nm (TBR)	1565 nm (TBR)
Lunar Relay to Lunar System (PNT and broadcast messaging) (Proximity Link)	S-Band	2492.028 MHz (2483.5-2500 MHz)	N/A
Search and Rescue (SAR) Alert Beacon	S-band	N/A	(TBD)
Multiple Access Return (MAR) (Proximity Link)	S-band	N/A	(TBD)

LCRNS.3.0361 S-band Forward Antenna Polarization (IOC)
The Lunar Relay Service shall transmit a Left Hand Circularly Polarized (LHCP) signal with an axial ratio of less than 3 dB for the S-band single access forward service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space. This definition is consistent with observing a counter-clockwise rotation when the electric field vector is viewed in the direction of propagation. 3 dB axial ratio has been selected as a realistically achievable performance target based

on historical space systems. **Note**: Although the addition of a RHCP signal of equivalent specification is optional for IOC (both LHCP or RHCP required for EOC), the Lunar Relay Service provider is *encouraged* to implement both polarizations for IOC to increase the early applicability and flexibility of service to Artemis and NASA vehicles.
Effectivity: IOC

LCRNS.3.0362 S-band Forward Antenna Polarization (EOC)
The Lunar Relay Service shall be capable of selecting LHCP or Right Hand Circularly Polarization (RHCP) with an axial ratio of less than 3 dB for each user link on the S-band Single Access Forward service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space. This definition is consistent with observing a counter-clockwise rotation when the electric field vector is viewed in the direction of propagation. A right-hand circularly polarized wave would have rotation in the opposite direction. 3 dB axial ratio has been selected as a realistically achievable performance target based on historical space systems. Having both LHCP and RHCP will be beneficial to support the greatest user flexibility.
Effectivity: EOC

LCRNS.3.0363 S-band Return Antenna Polarization (IOC)
The Lunar Relay Service shall receive a LHCP signal with an axial ratio of less than 3 dB for the S-band single access return service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space. This definition is consistent with observing a counter-clockwise rotation when the electric field vector is viewed in the direction of propagation. 3 dB axial ratio has been selected as a realistically achievable performance target based on historical space systems. **Note**: Although the addition of a RHCP signal of equivalent specification is optional for IOC (both LHCP or RHCP required for EOC), the Lunar Relay Service provider is *encouraged* to implement both polarizations for IOC to increase the early applicability and flexibility of service to Artemis and NASA vehicles.
Effectivity: IOC

LCRNS.3.0364 S-band Return Antenna Polarization (EOC)
The Lunar Relay Service shall be capable of selecting LHCP or RHCP with an axial ratio of less than 3 dB for each user link on the S-band Single Access Return service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space. This definition is consistent with observing a counter-clockwise rotation when the electric field vector is viewed in the direction of propagation. A right-hand circularly polarized rotates in the opposite direction. 3 dB axial ratio has been selected as a realistically achievable performance target based on historical space systems. Having both LHCP and RHCP will be beneficial to support the greatest user flexibility.
Effectivity: EOC

LCRNS.3.0365 Ka-band Forward Antenna Polarization
The Lunar Relay Service shall be capable of selecting LHCP or RHCP with an axial ratio of less than 3 dB for each user link on the Ka-band Forward service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space. This definition is consistent with observing a counter-clockwise rotation when the electric field vector is viewed in the direction of propagation. A right-hand circularly polarized wave rotates in the opposite direction. 3 dB axial ratio has been selected as a realistically achievable performance target based on historical space systems. Having both LHCP and RHCP will be beneficial to support the greatest user flexibility.
Effectivity: IOC, EOC

LCRNS.3.0366 Ka-band Return Antenna Polarization
The Lunar Relay Service shall be capable of selecting LHCP or RHCP with an axial ratio of less than 3 dB for each user link on the Ka-band Return service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates clockwise in space. This definition is consistent with observing a counter-clockwise rotation when the electric field vector is viewed in the direction of propagation. A

right-hand circularly polarized wave rotates in the opposite direction. 3 dB axial ratio has been selected as a realistically achievable performance target based on historical space systems. Having both LHCP and RHCP will be beneficial to support the greatest user flexibility.
Effectivity: IOC, EOC

LCRNS.3.0367 AFS Antenna Polarization
The Lunar Relay Service shall transmit an RHCP signal with an axial ratio of less than 3 dB for the AFS service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.
Rationale: Space systems typically use circular polarization to avoid the large mismatches possible with linear polarization. IEEE Standard 211-2018, IEEE Standard Definition of Terms for Radio Wave Propagation, defines a LHCP wave as a circularly or an elliptically polarized electromagnetic wave for which the electric field vector, when viewed with the wave approaching the observer, rotates counter-clockwise in space. This definition is consistent with observing a clockwise rotation when the electric field vector is viewed in the direction of propagation. RHCP is the LunaNet defined polarization for AFS. 3 dB axial ratio has been selected as a realistically achievable performance target based on historical space systems.
Effectivity: IOC, EOC

LCRNS.3.0370 Lunar Relay Proximity Signal Services
The Lunar Relay Service shall provide the LunaNet proximity service signals shown in Table 3-5. The Lunar Relay Service shall be capable of providing these services over the range of symbol rates specified in Table 3-5, and for all coding options specified in the LNIS V.4.
Rationale: Users must have knowledge of what services will be provided prior to system development. These signals were selected to provide IOC users their required services, while providing service providers the flexibility to implement more advanced signal types in later EOC phases. It is understood that many details within the LunaNet Interoperability Specification are TBR and under discussion, and those signals will be defined in future releases. The IOC signals shown here have priority for discussion and finalization.
Effectivity: See Table 3-5

Table 3-5 LunaNet Proximity Signal Service Requirements

LunaNet Signal ID (LNIS V4)	Symbol Rate Range	Purpose	Effectivity			
			IOC			EOC
			A	B	C	
PFS/PRS 1a	2 – 2,000 ksps	Simple Data Transmission (BPSK)	X	X	X	X
PFS/PRS 1b	48 – 100 ksps	Medium Rate w/ Ranging (PCM/PM/bi-phase-L)	X	X	X	X
PFS/PRS 1c	0.5 – 48 ksps	Low Data Rate w/ Ranging (PCM/PSK/PM)	X	X	X	X
PFS/PRS 1d	1 – 5 Msps	Spectrally Efficient High Data Rate (Filtered OQPSK/GMSK)				X
PFS/PRS 1e	1 – 5 Msps	High-Rate w/ Ranging (GMSK+PN)				X
PFS/PRS 2	[TBD]	CDMA Ranging (SS-BPSK or SS-UQPSK)				X
PFS 5	[TBD]	Augmented Forward Signal (AFS)	X	X	X	X
PRS 5	[TBD]	Multiple Access Return (SS-BPSK or SS-UQPSK)				X
PFKa/PRKa 1	1 – 100 Msps	Simple Data Transmission (BPSK/OQPSK)	X	X	X	X
PFKa/PRKa 2	1 – 100 Msps	Variable Coded Modulation (SCCC, DVB-S2, LDPC-VCM)				X
PFKa/PRKa 3	1 – 100 Msps	Spectrally Efficient High Data Rate (Filtered OQPSK/GMSK)				X
PFKa/PRKa 4	1 – 100 Msps	Ka-band Ranging (GMSK+PN)				X

LCRNS.3.0380 Lunar Relay Data Rate Services
The Lunar Relay Service shall provide data rate services to reference users as specified in Table 3-6.
Rationale: Table 3-6 provides the necessary information for minimum relay sizing, given a range of reference NASA user lunar platforms in IOC. Additional users with more demanding needs should be expected for EOC.
Effectivity: IOC

Table 3-6 Reference User System Performance and Data Rate Requirements

	S-band User Parameters				Ka-band User Parameters				Service Area
	Rtn Data Rate	EIRP	Fwd Data Rate	G/T	Rtn Data Rate	EIRP	Fwd Data Rate	G/T	
Crewed Landing System (i.e., HLS)	36 kbps	34 dBW	36 kbps	-5 dB/K	50 Mbps	53 dBW	10 Mbps	15 dB/K	SV2
Crewed Surface Vehicle (i.e., LTV)	10 kbps	28 dBW	10 kbps	-12 dB/K	5 Mbps	44 dBW	1 Mbps	6 dB/K	SV1
Robotic Orbiter/Lander	5 kbps	25 dBW	5 kbps	-15 dB/K	5 Mbps	44 dBW	1 Mbps	6 dB/K	SV2
CubeSat or Small Payload	1 kbps	18 dBW	1 kbps	-22 dB/K	1 Mbps	35 dBW	N/A	N/A	SV2
Quiescent Telemetry	0.25 kbps	11 dBW	0.25 kbps	-29 dB/K	N/A	N/A	N/A	N/A	SV3

Notes:

[1] All user system examples are best estimates of expected lunar systems. These values are intended to provide users and service providers with agreeable *minimum* performance requirements to design for. This ensures that users and service providers can develop systems in parallel that are compatible with each other.
[2] Link parameter examples shown here are just a subset of expected link parameters for Lunar Missions. Refer to the LunaNet Interoperability Specification for a larger list of signal types and options.
[3] User systems are likely to have multiple modes of operation. Users may have higher rate desired modes and lower rate contingency modes. Only required modes that drive relay performance (G/T, EIRP) are shown.
[4] It should be assumed that S-band links with data rates greater 30 kbps and Ka-band links with greater than 2 Mbps will use spectrally efficient modulation and coding such as BPSK (or OQPSK) with 7/8 LDPC. An Eb/N0 threshold of 4.1 dB at the LDPC decoder is recommended for a BER of 10^-8.
[5] For lower rate links (1 kbps ≤ S-band ≤ 30 kbps) and (Ka-band ≤ 2 Mbps) it may be assumed that power efficient modulation and coding will be used, such as PCM/PSK/PM with 1/2 LDPC. An Eb/N0 threshold of 2.8 dB at the LDPC decoder is recommended for a BER of 10^-8.
[6] For the Quiescent Telemetry link, it may be assumed that a lower BER of 10^-5 will be used. An Eb/N0 threshold of 1.7 dB at the Rate 1/2 LDPC decoder is recommended for a BER of 10^-5.
[7] Due to multipath signal interference caused by the Lunar surface, service providers should build 8 dB of multipath fading loss into link calculations to and from users on the Lunar Surface. As fading loss is determined by the pattern of the antenna located on the lunar surface and lunar surface topology, it will be the responsibility of the user to determine what elevation masking corresponds to 8 dB of fading loss and how that impacts coverage.
[8] 3 dB of implementation loss between the transmitter and receiver should be assumed on all links.
[9] It should be assumed that the user antenna axial ratio is 3 dB and that the polarization angle of the received wave is worst-case (90 degrees).

LCRNS.3.0390 Artemis Service Requirements (data volume)
Lunar Relay Services shall provide real-time data volume services shown in Table 3-7 for Artemis missions.
Rationale: The actual data volume transfer through the network is highly dependent on Artemis operations. The IOC-C estimate is for an active HLS or LTV sortie, under the assumptions noted. This requirement may be met using multiple relays.
Effectivity: IOC (per increment)

Table 3-7 Artemis Data Volume Service Requirements

Communications Service	Approximate Artemis Data Volumes (TBR)		
Increment	IOC-A	IOC-B	IOC-C
Return Link	3.1 Tbits/day	3.3 Tbits/day	6.5 Tbits/day
Return Link Volume Assumptions	17 hrs. Ka-Band + 9 hrs. S-Band	18 hrs. Ka-Band + 22 hrs. S-Band	36 hrs. Ka-Band + 44 hrs. S-Band
Forward Link	0.002 Tbits/day	0.7 Tbit/day	1.4 Tbit/day
Forward Link Volume Assumptions	0 hrs. Ka-Band + 17 hrs. S-Band	18 hrs. Ka-Band + 22 hrs. S-Band	36 hrs. Ka-Band + 44 hrs. S-Band
Earth day/hours. Cadence during active NASA human exploration lunar surface missions. Ka-Band @ 50 Mbps (return) and 10 Mbps (forward). S-Band @ 36 Kbps (return/forward). Data rates are specified as framed data rates, prior to forward error correction.			

LCRNS.3.0400 Aggregate Artemis Service Requirements (data rates)
The Lunar Relay Service shall provide three simultaneous real-time high-rate bidirectional links and three simultaneous low data rate bidirectional links to different users in SV2 as shown in Table 3-8 for Artemis missions.
Rationale: This requirement is needed to support the Artemis Base Camp (ABC) architecture. This estimate is for three active links at the same time, each at 60Mbps (180 Mbps total). This requirement may be met using multiple relays.
Effectivity: EOC

Table 3-8 Aggregate Artemis Data Rate Service Requirements

Communications Service	Artemis Data Rate [1]
Low Data-Rate Return Link	36 kbps x 3
Low Data-Rate Forward Link	36 kbps x 3
High Data-Rate Return Link	60 Mbps x 3
High Data-Rate Forward Link	10 Mbps x 3
[1] Data rates are specified as framed data rates, prior to forward error correction.	

LCRNS.3.0410 Aggregate Artemis Service Requirements (data volume)
Lunar Relay Services shall provide real-time aggregate data volume services shown in Table 3-9 for Artemis missions.
Rationale: The actual data volume transfer through the network is highly dependent on Artemis operations. This estimate is for active HLS, LTV, and ABC operations at the same time, under the assumptions noted. This requirement may be met using multiple relays.
Effectivity: EOC

Table 3-9 Aggregate Artemis Data Volume Service Requirements

Communications Service	Artemis Data Volume [1]
Return Link	6.5 Tbits/day (TBR) x 3
Forward Link	1.4 Tbits/day (TBR) x 3
[1] Approximately real-time 24-hour high-data-rate, and 24-hour low data rate cadence per day for each link during active NASA human exploration lunar surface missions.	

LCRNS.3.0420 Antenna Auto-Tracking
The Lunar Relay Service shall provide the capability to track users and maintain the communications link during nominal and off-nominal user trajectories for both S-band and Ka-band services. If the service uses narrow beam antennas that do not cover the entire service volume, then the antennas shall have some form of auto-tracking to ensure that the link is maintained.
Rationale: The ability to track nominal and off-nominal trajectories will be critical in ensuring crew safety during anomalies and for ascent and descent scenarios.
Effectivity: IOC-B, IOC-C, EOC

LCRNS.3.0421 Forward Signal Acquisition
The Lunar Relay Service shall provide a swept unmodulated carrier during forward acquisition.
Rationale: This is a service that modern ground stations provide, and spacecraft missions have come to expect- does not include AFS service.
Effectivity: IOC, EOC

LCRNS.3.0422 Return Signal Acquisition
The Lunar Relay Service shall be capable of locking onto a modulated carrier during return acquisition.
Rationale: It is commonplace to put the burden of acquisition on the network side in order to reduce complexity of the user mission. This is a capability that modern ground stations have.
Effectivity: IOC, EOC

LCRNS.3.0470 Dynamic Signal
The Lunar Relay Service shall be capable of maintaining the communication and navigation links through the dynamic mission reference trajectories shown in Appendix B [TBR].

Rationale: This requirement implies that the relay system receiver must meet Doppler tracking requirements and antenna slewing or beamforming requirements to support dynamic mission phases.
Effectivity: IOC, EOC

LCRNS.3.0490 Cross-Link Capability
The Lunar Relay Service shall provide interoperable cross link support between its own nodes and those nodes of other service providers per the LunaNet Interoperability Specification to provide for communication, data services, and intersatellite PNT.
Rationale: Assumes multiple providers working together within one lunar communications and navigation network. Providers are expected to develop capabilities to support waveforms and protocols to communicate with other provider's satellites, measure intersatellite range and Doppler, exchange and synchronize time, and exchange position and velocity as well navigation sources in compliance with the LunaNet interoperability specification among their own nodes and with other providers independent from Earth.
Effectivity: EOC

3.2.2 Space Internetworking Data Service Requirements

The network requirements are the aggregation of requirements for all data flows between all sources and destinations flowing through lunar relay services.

LCRNS.3.0500 Data Service Capabilities
The Lunar Relay service shall implement in-space data service capabilities to support routing of all received user data to the appropriate destination, either with minimal latency/real-time (starting with IOC-A), or through store-and-forward (no later than IOC-C)
Rationale: For each unit of data received from the user, the Lunar Relay service must be able to use methods to understand the received user data (e.g., reading headers, etc.) and, in real-time, act on such information where routing, QoS, and other relevant functionality is required. The lunar relay service needs to provide real-time service for those users having specific low latency requirements and provide store and forward service to those users with flexible latency requirements.
Effectivity: IOC, EOC

LCRNS.3.0510 Protocol Configuration
The Lunar Relay Service shall be able to configure their protocol to communicate with all compatible user missions.
Rationale: Users requesting data service from the lunar relay service need to understand which nodes support the unique protocol configurations and constraints of their configurations which must be followed when connecting to various relay nodes.
Effectivity: IOC, EOC

LCRNS.3.0520 Store and Forward/Disruption Tolerant Network (DTN)
The Lunar Relay Service shall implement DTN BPv7 with custody transfer to provide store and forward data transfers.
Rationale: DTN is the most effective means of ensuring data delivery when disruptions to signal path occur and are extensible to the entire solar system. The lunar relay service needs to provide real-time service for those users having specific low latency requirements and provide store and forward service to those users with flexible latency requirements.
Effectivity: IOC-C, EOC

LCRNS.3.0530 DTN Reliability
The Lunar Relay Service DTN shall provide reliable delivery of bundles at or exceeding 95% (TBR) successful delivery.
Rationale: User missions rely on the lunar relay services to provide consistent and dependable service to receive and distribute mission data. Reliable delivery of bundle service is dependent on the availability of the overall lunar relay network.
Effectivity: IOC-C, EOC

LCRNS.3.0540 DTN Routing Rate
The Lunar Relay DTN Service shall provide a minimum bundle generation and throughput rate no less than the maximum relay data rates as defined in this document.
Rationale: DTN service data ingest, processing, storage, and output rates must not be a bottleneck in data throughput, and so must process inbound and outbound data as fast as or faster than the maximum aggregate input and output rates of all communications channels that use DTN, and consistent with available per-minute contact times.
Effectivity: IOC-C, EOC

LCRNS.3.0550 DTN Storage Accounting
The Lunar Relay DTN Service shall maintain a centralized storage of service accounting and network and node status information and make this accessible for accounting purposes.
Rationale: The NSN will need to collect, store and account for user data to meet user needs and required QOS metrics.
Effectivity: IOC-C, EOC

LCRNS.3.0560 Intermediate DTN Bundle Storage
The Lunar Relay DTN Services shall be capable of storing bundles at intermediate relay nodes during bundle routing.
Rationale: The relays will need to provide sufficient intermediate storage of data to meet mission requirements and provide accounting information for such data to satisfy user data accounting needs.
Effectivity: IOC-C, EOC

3.2.3 Position, Navigation, and Timing (PNT) Services

The lunar communications and navigation service shall provide functionality for in-situ autonomous lunar orbiting and surface asset navigation and time knowledge to meet their mission requirements. PNT services support crewed and robotic spacecraft and surface activities, particularly during dynamic phases (low-lunar orbit, during descent and ascent, and during long EVAs) and surface operations. Table 3-10 describes representative user scenarios and their associated position, velocity, and time (PVT) performance requirements for the IOC increments and EOC. Note that Table 3-10 specifies performance for the final increment of IOC when user performance is required to be met. However, it is expected that IOC-A and IOC-B will verify some of these user PNT requirements. PVT performance in this table includes position, velocity, and time knowledge, time to achieve the first fix of those knowledge levels, and the time delay to meet knowledge updates. All position and velocity numbers are given as RSS values of position and velocity component errors, except for the Powered Descent Initiation (PDI) to Landing scenario. From PDI through the descent sequence, the values are RSS; at the time of landing, the values are specified for position as a radius on the surface and a velocity requirement per axis. *Time to first fix* is defined as the time it takes to get an initial fix in the scenario environment, or time to recover the position knowledge after a propulsive maneuver (except landing) needed to meet the position and/or velocity knowledge requirement(s). *Time delay to meet knowledge* is the time it takes to update position and/or velocity and time knowledge (when relays are in view) and this includes landing scenario radiometric update rate.

There are currently four user scenarios defined for PNT. The first scenario represents an asset in a circular low lunar orbit (LLO) (approximately ≤ 100 km from the lunar surface). The navigation solution in that case can either be accomplished on the ground or on-board, depending on the user's operational concept. The second scenario provides the requirement on PVT knowledge prior to performing the De-orbit Insertion (DOI) to leave LLO. The third scenario describes lander type missions at the time prior to starting their powered descent to the surface (PDI) (e.g., at approximately 15 km from the lunar surface) all the way through landing. The state and time knowledge in that user scenario is primarily envisioned to initialize an on-board full 6-Degree of Freedom (DOF) solution with timely updates from multiple data sources, including radiometrics from the lunar relay. The landing requirement addresses the knowledge portion of a given landing touchdown, assuming that the lander is equipped with hazard detection capabilities. The remaining user case relates to PVT knowledge during surface activities. While there are several sub-scenarios, these have been generalized to absolute knowledge for surface activities. For the IOC-C increment, a lunar rover is envisioned as part of the surface traversing user case with higher speeds (e.g., approximately 10 km/h moving speed). In addition, relative PVT knowledge becomes necessary between two surface assets (human and robotic) or a surface asset and a surface terrain feature. In this user scenario, the lunar relay service contributes to meeting the relative knowledge requirements but is not the sole observation set.

LCRNS.3.0570 Position, Navigation, and Timing - User
The Lunar Relay Service shall provide PNT services such that user PNT performance (TBR) listed in Table 3-10 are met, specified in a lunar-centric inertial frame.
Rationale: Table 3-10 provides the current government best estimate of user needs and can be used by providers to scope the required performance of their system.
Effectivity: IOC-C, EOC

Table 3-10 Representative User Scenario PNT Performance Requirements

	Lander/Orbiter - Low Lunar Orbit	Lander - Prior to De-Orbit Insertion	Powered Descent Initiation to Landing	General Surface
Position Knowledge (m) (3-sigma value)	100	100	25 radius[1]	± 10 absolute; < 10 relative[2]
Velocity Knowledge (m/s) (3-sigma value)	0.01	0.05	0.1 3D[3]	N/A[4]
Time to First Fix (s) - Time Delay to meet Knowledge	3600	-1200[5]	-900[6]	600
Time Delay to meet Knowledge Update (s)	30	1	1[7]	1
Time Knowledge (ms)	0.10	0.10	0.10	0.10

NOTE: All values are specified relative to the (TBS) lunar reference frame.

[1] Assumes user capability includes Hazard Detection/Avoidance system; requirement is per axis until landing at which point it is the RSS of the lateral directions as represented by radius from landing target.
[2] Relative to another surface asset or feature; requirement is not fully allocated to the Lunar Relay, however radiometrics from Lunar Relay contribute to relative knowledge solution.
[3] 3D means per axis.
[4] Assumes path ill-defined and velocity results from differencing of previous and current position measurement.
[5] Not time to first fix, but rather is time prior to Descent Orbit Insertion when knowledge requirement must be met.
[6] Not time to first fix, but rather is time prior to PDI assuming a maximum of 30 minutes to achieve the PVT performance.
[7] Update rate using radiometrics and supplemental user-onboard sensor suite ; map update may be provided as part of the messaging service.

LCRNS.3.0590 Lunar Relay Predictive Ephemeris for Network Support
The relay orbit predicted ephemeris shall support network planning, scheduling, and acquisition activities.
Rationale: Relay ephemerides are needed by the NSN and users to perform service scheduling and service planning, and for users to acquire services from service providers.
Effectivity: IOC, EOC

LCRNS.3.0600 Position, Navigation, and Timing (Service Reference Signals)

The Lunar Relay Service shall provide pseudorange (PR) and 1-way forward Doppler reference signals with signal-in-space-errors (SISE) contributions as specified in Table 3-11 or better.

Rationale: The Lunar Relay Service shall be capable of providing reference signals that can be used by all assets at any time to calculate their own position, velocity, and time. SISE include errors from: relay on-board state knowledge (position, velocity and time), signal integrity and on-board path delays, predicted relay states conveyed to users, and states and time representation. SISE does not include delays and phase noise introduced by the user system.

Effectivity: IOC, EOC

Table 3-11 Lunar Relay PNT Reference Signal Source SISE Requirements

Error	Value
SISE Position	13.43 m (3-sigma)
SISE Velocity	1.2 mm/s (3-sigma) @ 10 sec

LCRNS.3.0610 Position, Navigation, and Timing (Service 2-way Measurements)

The lunar relays shall be capable of providing 2-way Coherent Ranging and 2-way Coherent Doppler with Measurement-in-Space-Errors (MISE) contributions as specified in Table 3-12 or better.

Rationale: The lunar relays shall be capable of providing 2-way metric tracking measurements, especially for users that do not accommodate the use of 1-way reference signals. MISE include errors from: relay on-board signal implementation, signal integrity, and residual on-board path delays. MISE does not include delays, phase noise, or ephemeris errors introduced by the user system, nor does it include ephemeris and time errors onboard the relay as identified in the contribution to SISE.

Effectivity: IOC, EOC

Table 3-12 Lunar Relay PNT Coherent Measurement MISE Requirements

Error	Value
MISE Range [1]	0.93 m (3-sigma) @ 10 sec
MISE Doppler [1], [2]	0.33 mm/s (3-sigma) @ 10 sec
[1] Error represented as one-way [2] Based on an assumed signal power level on RF path	

LCRNS.3.0620 Interoperability of PNT Services
The Lunar Relay Service shall have the ability to provide the messages defined in the LunaNet Interoperability Specification, commensurate with Table 3-11 and Table 3-12.
Rationale: Service interoperability is essential to behave as a single functional network composed of contributions from multiple LNSPs.
Effectivity: IOC, EOC

3.2.4 Lunar Search and Rescue (LunarSAR) Services

LCRNS.3.0630 LunarSAR Emitter Probability of Detection
The Lunar Relay Service shall provide a probability of detection of 99% within 5 minutes [TBR] of activation, for a LunarSAR beacon transmitting a LunarSAR-compliant message at 35 dBm [TBR] EIRP.
Rationale: High probability of detection is required to ensure timely distress rescue coordination and response for future governmental, commercial, and private lunar exploration efforts utilizing internationally standardized LunarSAR message formatting and transmission EIRP requirements.
Effectivity: EOC

LCRNS.3.0640 LunarSAR Detection Dissemination
The Lunar Relay Service shall notify Relay users of LunarSAR beacon detection within 5 minutes [TBR] of beacon activation.
Rationale: Distress event dissemination is a key cornerstone of SAR operations, and consequent lunar surface actions.
Effectivity: EOC

LCRNS.3.0650 LunarSAR Service Availability
The Lunar Relay Service shall provide LunarSAR Service availability of 99% (TBR) during scheduled EVA periods.
Rationale: High availability rates are required to ensure timely distress rescue coordination and response for future governmental, commercial, and private lunar exploration efforts utilizing internationally standardized LunarSAR message formatting and transmission EIRP requirements. High coverage percentages are paced with the development of the overall lunar concept of operations, i.e., as Artemis focuses on lunar south pole activities, LunarSAR service availability will evolve in the lunar south pole. Lunar Relay Service and EVA schedules may be coordinated to meet this requirement.
Effectivity: EOC

LCRNS.3.0660 LunarSAR Message Relay Timeline
The Lunar Relay Service shall relay the entire beacon message(s), beacon encoded position(s), and timestamps to Earth and selected lunar surface locations within 5 minutes [TBR] of beacon activation.
Rationale: The timeline between LunarSAR beacon activation and reception/processing of LunarSAR data drives response timeframes and ability to

successfully perform crewmember rescue operations over extended EVA walk-back distances. Future SAR cases may involve a mixed ecosystem of commercial, international, and governmental users requiring timely coordination and ability to disseminate information.
Effectivity: EOC

LCRNS.3.0670 LunarSAR Independent Location Probability
The Lunar Relay Service shall provide a probability of independent location (not relying on LunarSAR beacon-provided location data) of 95% within 10 minutes [TBR] of activation, for a LunarSAR beacon transmitting at 35 [TBR] dBm EIRP.
Rationale: As a future capability, the relay constellations should provide "reverse GPS" for disadvantaged users in potentially PNT-degraded environments (i.e., PNT signal terrain masking or other terrain features causing multipath propagation effects). This aligns with current terrestrial satellite-aided search and rescue (SARSAT) principles for those in potentially degraded GNSS environments.
Effectivity: EOC

LCRNS.3.0680 LunarSAR Independent Location Accuracy
The Lunar Relay Service shall locate an emergency beacon within the Lunar South Pole region with an accuracy of 50 meters [TBR], without reliance on the beacon's self-reported position for a LunarSAR beacon transmitting at 35 [TBR] dBm EIRP.
Rationale: As a future capability, The LCRNS relay constellations should provide "reverse Global Positioning System (GPS)" for disadvantaged users in potentially PNT-degraded environments (i.e., PNT signal terrain masking or other terrain features causing multipath propagation effects). This aligns with current terrestrial satellite-aided search and rescue (SARSAT) principles for those in potentially degraded GNSS environments.
Effectivity: EOC

3.2.5 Lunar Relay Service On-orbit Validation Capabilities

LCRNS.3.0690 On-board self and built-in service testing
Each Lunar Relay service node shall have internal built-in test and verification capability.
Rationale: Unlike typical earth communication relays, the lunar relay nodes will be performing other services to route, store and forward user data and provide accurate location and position information with lunar user elements. Some method of verifying these services (or degraded services) must be internal to the relay to validate prior to operational certification with the possibility there may not be lunar users available to test services. This includes verifying its operation after recovery from critical faults on-orbit.
Effectivity: IOC, EOC

3.2.6 Lunar Relay Cybersecurity

LCRNS.3.0700 Command Data Encryption
Each Lunar Relay service node shall use FIPS 140-3 certified encryption for all spacecraft commands.
Rationale: Command data must be protected to ensure that only authorized users have access to the system and all services are available during critical events. This must be verified against the NIST FIPS 140-3 Cryptographic Module Validation Program and the communication path must be tested to ensure compatibility between ground infrastructure and space segment prior to launch.
Effectivity: IOC, EOC

LCRNS.3.0710 Information System Authorization
The lunar relay providers ground system shall be assessed and authorized as a HIGH system in accordance with the Federal Information System Management Act of 2014 using NIST Special Publication 800-53, Revision 5.
Rationale: All systems processing data for or on behalf of NASA are required to follow the NIST Risk Management Framework and conduct regular assessments and perform continuous monitoring activities.
Effectivity: IOC, EOC

LCRNS.3.0720 Project Protection Plan
The lunar relay provider shall complete and update a Project Protection Plan (PPP) to identify known threats and response plans to mitigate associated risks.
Rationale: NASA requires each flight system to complete and maintain a PPP that addresses known risks identified in NASA-STD-1006.
Effectivity: IOC, EOC

LCRNS.3.0730 Service Authentication
The lunar relay PNT service shall have the capability to provide authentication to users.
Rationale: The use of authentication will provide resistance to spoofing and ensure that PNT data is coming from a legitimate source.
Effectivity: IOC, EOC

LCRNS.3.0740 Service Availability Protection
The lunar relay system shall have anti-jamming capabilities to prevent denial of service via Radio Frequency Interference (RFI) or other electronic attack.
Rationale: The inclusion of anti-jamming capabilities will help ensure that events could not be intentionally disrupted by a malicious actor.
Effectivity: EOC

Appendix A. Effectivity and Compliance

Note: IOC capabilities form the set of *threshold* requirements that shall be met by a LNSP. EOC capabilities can be implemented initially but are not part of the threshold set.

Table A-1 Effectivity and Compliance Matrix

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
			IOC-A	IOC-B	IOC-C	EOC	
LCRNS.3.0010	Interoperability and Compatibility	The Lunar Relay service shall comply with the interfaces specified in the LunaNet Interoperability Specification LNIS V.4 (ESC-LCRNS-SPEC-0015) per the compliance matrix in Appendix C.	X	X	X	X	
LCRNS.3.0020	Lunar Relay Communications Function	The Lunar Relay Service shall provide key operational support to lunar systems.	X	X	X	X	
LCRNS.3.0030	Lunar Relay Ubiquitous Signal for Position, Navigation, and Timing and Broadcast Messaging Service	The Lunar Relay service shall provide Augmented Forward Signals (AFS) with broadcast messaging.	X	X	X	X	
LCRNS.3.0040	Lunar Relay Position, Navigation,	The Lunar Relay service shall provide functionality via dedicated service for	X	X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
	and Timing Function	in-situ autonomous lunar orbiting and surface asset navigation and time knowledge.					
LCRNS.3.0050	Lunar Relay Real-time Data Service Functionality	The Lunar Relay Service shall provide a lunar communications relay capable of real-time data relay services between Earth and Lunar Users.	X	X	X	X	
LCRNS.3.0060	Lunar Relay Non-Real-Time Data Service Functionality	The Lunar Relay Service shall provide a lunar communications relay capable of store-and-forward data relay services between Earth and Lunar Users.			X	X	
LCRNS.3.0070	Relay between Lunar Users (Real-Time Data Service)	The Lunar Relay Service shall provide a lunar communications relay capable of real-time data relay services between Lunar Users.				X	
LCRNS.3.0080	Relay between Lunar Users (Non-Real-Time Data Service)	The Lunar Relay service shall provide a lunar communications relay capable of store-and-forward data relay services between Lunar Users.				X	
LCRNS.3.0090	Operational Service Availability (nominal IOC)	The Lunar Relay Service shall provide nominal operational service Availability as	X	X	X		Per Table 3-1

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		shown in Table 3-1 for each of the IOC increments, averaged over a period of one Earth month.					
LCRNS.3.0091	Operational Service Availability (critical IOC)	The Lunar Relay Service shall provide critical operational service Availability as shown in Table 3-1 for each of the IOC increments, averaged over a period of one Earth month.		X	X		Per Table 3-1
LCRNS.3.0092	Operational Service Availability (nominal EOC)	The Lunar Relay Service shall provide nominal operational service Availability as shown in Table 3-2 for EOC, averaged over a period of one Earth month.				X	
LCRNS.3.0093	Operational Service Availability (critical EOC)	The Lunar Relay Service shall provide critical event operational service Availability per Table 3-2 for EOC, averaged over a period of one Earth month.				X	
LCRNS.3.0095	Simultaneous Service to Multiple Users (Real Time)	The Lunar Relay Service shall provide simultaneous services as shown in Table 3-3 for each IOC increment and EOC. All Ka-band, S-band, and AFS services shown for a given subphase/phase are	X	X	X	X	Per Table 3-3

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		simultaneous to each other.					
LCRNS.3.0096	Service Volume (Phasing)	The Lunar Relay Service shall provide services within the Service Volumes shown in Table 3-3 for each of the IOC increments and EOC.	X	X	X	X	Per Table 3-3
LCRNS.3.0097	Service Coverage (Phasing)	The Lunar Relay Service shall provide coverage within the minimum Service Volumes as shown in Table 3-3 for each of the IOC increments and EOC.	X	X	X	X	Per Table 3-3
LCRNS.3.0100	Ka-Band Return Data Services Relay Network Coverage	The Lunar Relay Service shall provide dedicated Ka-band return data services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.	X	X	X	X	Per Table 3-3
LCRNS.3.0105	Ka-Band Forward Data Services Relay Network Coverage	The Lunar Relay Service shall provide dedicated Ka-band forward data services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.		X	X	X	Per Table 3-3
LCRNS.3.0110	S-Band Return Data Services Relay Network Coverage	The Lunar Relay Service shall provide dedicated S-band return data services to lunar users within the applicable service volume and	X	X	X	X	Per Table 3-3

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		at the percent coverage levels shown in Table 3-3.					
LCRNS.3.0113	S-Band Forward Data Services Relay Network Coverage	The Lunar Relay Service shall provide dedicated S-band forward coverage to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.	X	X	X	X	Per Table 3-3
LCRNS.3.0115	Point-to-Point PNT Services Relay Network Coverage	The Lunar Relay Service shall provide Point-to-Point link PNT services to lunar users within the applicable service volume and at the percent coverage levels shown in Table 3-3.	X	X	X	X	Per Table 3-3
LCRNS.3.0120	Lunar Augmented Navigation System (LANS) Service	The Lunar Relay Service shall provide Lunar Augmented Navigation System (LANS) services within the Service Volumes shown in Table 3-3.			X	X	Per Table 3-3
LCRNS.3.0130	LANS Service Geometric Dilution of Precision (GDOP)	The Lunar Relay Service shall provide LANS services with Geometric Dilution of Precision (GDOP) <6 (TBR) in the Service Volumes identified in Table 3-3.			X	X	Per Table 3-3
LCRNS.3.0140	Lunar Service Situational Awareness	The Lunar Relay Service shall share relay ephemeris knowledge with other providers.	X	X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
LCRNS.3.0150	Time Synchronization	The Lunar Relay Service shall synchronize time with an external common reference timing source shared with other providers.	X	X	X	X	
LCRNS.3.0160	Provider to Provider Message Exchange	The Lunar Relay Service shall support messaging services between different providers, enabling exchange of navigation, schedule and space situational awareness information.				X	
LCRNS.3.0170	Dynamic Phases	The Lunar Relay Service shall cover dynamic events such as lunar vehicle descent and ascent, lunar orbiting vehicles, and mobility surface vehicles and personnel.	X	X	X	X	
LCRNS.3.0180	Dynamic Coverage– Low Lunar Orbit (LLO)	The Lunar Relay service shall provide communications and PNT services to crewed and robotic vehicles in a low lunar orbit (LLO) within the applicable service volume and at the percent coverage levels shown in Table 3-3.	X	X	X	X	Per Table 3-3
LCRNS.3.0190	Dynamic Coverage – Descent (IOC)	The Lunar Relay Service shall provide communications and PNT services to crewed and robotic vehicles while	X	X	X		Per Table 3-3

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		descending to the lunar surface from LLO within the applicable service volume and at the percent coverage shown in Table 3-3.					
LCRNS.3.0195	Dynamic Coverage – Descent (EOC)	The Lunar Relay Service shall provide continuous communications and PNT services to crewed vehicles while descending to the lunar surface from LLO within SV3 (Table 3-3).				X	Per Table 3-3
LCRNS.3.0200	Dynamic Coverage – Ascent (IOC)	The Lunar Relay Service shall provide communications and PNT services to crewed and robotic vehicles while in ascent from the lunar surface to LLO within the applicable service volume and at the percent coverage levels shown in Table 3-3.	X	X	X		Per Table 3-3
LCRNS.3.0205	Dynamic Coverage – Ascent (EOC)	The Lunar Relay Service shall provide continuous communications and PNT services to crewed vehicles while in ascent from the lunar surface to LLO within SV3 (Table 3-3).				X	Per Table 3-3
LCRNS.3.0210	Surface User Operations Coverage (generic)	The Lunar Relay Service shall provide communications and PNT services to	X	X	X	X	Per Table 3-3

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		users while on the lunar surface within the applicable service volumes shown in Table 3-3.					
LCRNS.3.0220	Crewed Surface Operations	The Lunar Relay Service shall provide communications and PNT services to crewed surface vehicle users within the applicable service volumes shown in Table 3-3.	X	X	X	X	Per Table 3-3
LCRNS.3.0230	EVA surface extended Operations Duration	The Lunar Relay Service shall provide navigation services such that the NASA human spaceflight architecture on the lunar surface can meet a minimum of 24 hours of cumulative surface EVA time per crewmember per 7 Earth-day period during surface stays greater than or equal to 14 Earth-days.				X	
LCRNS.3.0240	EVA surface initial Operations Duration	The Lunar Relay Service shall provide PNT services so that the initial Artemis systems can be capable of supporting at least two lunar surface extra-vehicular activities (EVA), each lasting at least 4 hours nominally plus 1 hour contingency.			X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
LCRNS.3.0260	User Data Security	The Lunar Relay Service shall maintain user provided encryption sent to and from the lunar relays and Earth ground stations.	X	X	X	X	
LCRNS.3.0270	Earth Independent Services	The Lunar Relay Service shall provide services between endpoints in the lunar vicinity without routing data to and from Earth.				X	
LCRNS.3.0280	Service Provider Real-time Data Latency	The Lunar Relay Service node shall limit the time between receiving real-time data and transmitting that data to the NSN interface point to less than 1.0 (TBR) seconds.	X	X	X	X	
LCRNS.3.0310	Service Provider Earth Forward or Return Latency	The Lunar Relay Service shall limit the time between receiving/transmitting real-time data from a user to and from the NSN interface point to less than 3.0 (TBR) seconds each way.	X	X	X	X	
LCRNS.3.0320	Concurrency of Operations	The Lunar Relay Service shall provide concurrent operations of relay services for lunar communications, data operations, PNT services, and LunaNet messaging services.	X	X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
LCRNS.3.0340	Ground Station (commercial or government) Interface to the NSN	The Lunar Relay Service shall interface with the NSN at the NSN demarcation point in the Cloud.	X	X	X	X	
LCRNS.3.0350	Quality of Service (QOS) metrics	The Lunar Relay Service shall provide real-time status and Quality of Service (QOS) metrics to the NSN.	X	X	X	X	
LCRNS.3.0360	Lunar Relay Frequency Band Requirements	The Lunar Relay Service shall provide the frequency band services per Table 3-4.	X	X	X	X	Per Table 3-4
LCRNS.3.0361	S-band Forward Antenna Polarization (IOC)	The Lunar Relay Service shall transmit a Left Hand Circularly Polarized (LHCP) signal with an axial ratio of less than 3 dB for the S-band single access forward service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.	X	X	X		
LCRNS.3.0362	S-band Forward Antenna Polarization (EOC)	The Lunar Relay Service shall be capable of selecting LHCP or Right Hand Circularly Polarization (RHCP) with an axial ratio of less than 3 dB for each user link on the S-band Single Access Forward service. The 3 dB				X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		axial ratio shall be met over the full operational beamwidth of the antenna.					
LCRNS.3.0363	S-band Return Antenna Polarization (IOC)	The Lunar Relay Service shall receive a LHCP signal with an axial ratio of less than 3 dB for the S-band single access return service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.	X	X	X		
LCRNS.3.0364	S-band Return Antenna Polarization (EOC)	The Lunar Relay Service shall be capable of selecting LHCP or RHCP with an axial ratio of less than 3 dB for each user link on the S-band Single Access Return service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.				X	
LCRNS.3.0365	Ka-band Forward Antenna Polarization	The Lunar Relay Service shall be capable of selecting LHCP or RHCP with an axial ratio of less than 3 dB for each user link on the Ka-band Forward service. The 3 dB axial ratio shall be met over the full operational	X	X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		beamwidth of the antenna.					
LCRNS.3.0366	Ka-band Return Antenna Polarization	The Lunar Relay Service shall be capable of selecting LHCP or RHCP with an axial ratio of less than 3 dB for each user link on the Ka-band Return service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.	X	X	X	X	
LCRNS.3.0367	AFS Antenna Polarization	The Lunar Relay Service shall transmit an RHCP signal with an axial ratio of less than 3 dB for the AFS service. The 3 dB axial ratio shall be met over the full operational beamwidth of the antenna.	X	X	X	X	
LCRNS.3.0370	Lunar Relay Proximity Signal Services	The Lunar Relay Service shall provide the LunaNet proximity service signals shown in Table 3-5. The Lunar Relay Service shall be capable of providing these services over the range of symbol rates specified in Table 3-5, and for all coding options specified in the LNIS V.4.	X	X	X	X	Per Table 3-5

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
LCRNS.3.0380	Lunar Relay Data Rate Services	The Lunar Relay Service shall provide data rate services to reference users as specified in Table 3-6.	X	X	X		Per Table 3-6
LCRNS.3.0390	Artemis Service Requirements (data volume)	Lunar Relay Services shall provide real-time data volume services shown in Table 3-7 for Artemis missions.	X	X	X		Per Table 3-7
LCRNS.3.0400	Aggregate Artemis Service Requirements (data rates)	The Lunar Relay Service shall provide three simultaneous real-time high-rate bidirectional links and three simultaneous low data rate bidirectional links to different users in SV2 as shown in Table 3-8 for Artemis missions.				X	Per Table 3-8
LCRNS.3.0410	Aggregate Artemis Service Requirements (data volume)	Lunar Relay Services shall provide real-time aggregate data volume services shown in Table 3-9 for Artemis missions.				X	Per Table 3-9
LCRNS.3.0420	Antenna Auto-Tracking	The Lunar Relay Service shall provide the capability to track users and maintain the communications link during nominal and off-nominal user trajectories for both S-band and Ka-band services. If the service uses narrow beam antennas that do not cover the entire service		X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		volume, then the antennas shall have some form of auto-tracking to ensure that the link is maintained.					
LCRNS.3.0421	Forward Signal Acquisition	The Lunar Relay Service shall provide a swept unmodulated carrier during forward acquisition.	X	X	X	X	
LCRNS.3.0422	Return Signal Acquisition	The Lunar Relay Service shall be capable of locking onto a modulated carrier during return acquisition.	X	X	X	X	
LCRNS.3.0470	Dynamic Signal	The Lunar Relay Service shall be capable of maintaining the communication and navigation links through the dynamic mission reference trajectories shown in Appendix B [TBR].	X	X	X	X	
LCRNS.3.0490	Cross-Link Capability	The Lunar Relay Service shall provide interoperable cross link support between its own nodes and those nodes of other service providers per the LunaNet Interoperability Specification to provide for communication, data services, and intersatellite PNT.				X	
LCRNS.3.0500	Data Service Capabilities	The Lunar Relay service shall implement in-space	X	X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		data service capabilities to support routing of all received user data to the appropriate destination, either with minimal latency/real-time (starting with IOC-A) , or through store-and-forward (no later than IOC-C)					
LCRNS.3.0510	Protocol Configuration	The Lunar Relay Service shall be able to configure their protocol to communicate with all compatible user missions.	X	X	X	X	
LCRNS.3.0520	Store and Forward/Disruption Tolerant Network (DTN)	The Lunar Relay Service shall implement DTN BPv7 with custody transfer to provide store and forward data transfers.			X	X	
LCRNS.3.0530	DTN Reliability	The Lunar Relay Service DTN shall provide reliable delivery of bundles at or exceeding 95% (TBR) successful delivery.			X	X	
LCRNS.3.0540	DTN Routing Rate	The Lunar Relay DTN Service shall provide a minimum bundle generation and throughput rate no less than the maximum relay data rates as defined in this document.			X	X	
LCRNS.3.0550	DTN Storage Accounting	The Lunar Relay DTN Service shall			X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
		maintain a centralized storage of service accounting and network and node status information and make this accessible for accounting purposes.					
LCRNS.3.0560	Intermediate DTN Bundle Storage	The Lunar Relay DTN Services shall be capable of storing bundles at intermediate relay nodes during bundle routing.			X	X	
LCRNS.3.0570	Position, Navigation, and Timing - User	The Lunar Relay Service shall provide PNT services such that user PNT performance (TBR) listed in Table 3-10 are met, specified in a lunar-centric inertial frame.			X	X	Per Table 3-10
LCRNS.3.0590	Lunar Relay Predictive Ephemeris for Network Support	The relay orbit predicted ephemeris error shall support network planning, scheduling, and acquisition activities.	X	X	X	X	
LCRNS.3.0600	Position, Navigation, and Timing (Service Reference Signals)	The Lunar Relay Service shall provide pseudorange (PR) and 1-way forward Doppler reference signals with signal-in-space-errors (SISE) contributions as specified in Table 3-11 or better.	X	X	X	X	Per Table 3-11
LCRNS.3.0610	Position, Navigation, and Timing	The lunar relays shall be capable of providing 2-way	X	X	X	X	Per Table 3-12

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
	(Service 2-way Measurements)	Coherent Ranging and 2-way Coherent Doppler with Measurement-in-Space-Errors (MISE) contributions as specified in Table 3-12 or better.					
LCRNS.3.0620	Interoperability of PNT Services	The Lunar Relay Service shall have the ability to provide the messages defined in the LunaNet Interoperability Specification, commensurate with Table 3-11 and Table 3-12.	X	X	X	X	Per Table 3-11 and Table 3-12
LCRNS.3.0630	LunarSAR Emitter Probability of Detection	The Lunar Relay Service shall provide a probability of detection of 99% within 5 minutes [TBR] of activation, for a LunarSAR beacon transmitting a LunarSAR-compliant message at 35 dBm [TBR] EIRP.				X	
LCRNS.3.0640	LunarSAR Detection Dissemination	The Lunar Relay Service shall notify Relay users of LunarSAR beacon detection within 5 minutes [TBR] of beacon activation.				X	
LCRNS.3.0650	LunarSAR Service Availability	The Lunar Relay Service shall provide LunarSAR Service availability of 99% (TBR) during scheduled EVA periods.				X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
LCRNS.3.0660	LunarSAR Message Relay Timeline	The Lunar Relay Service shall relay the entire beacon message(s), beacon encoded position(s), and timestamps to Earth and selected lunar surface locations within 5 minutes [TBR] of beacon activation.				X	
LCRNS.3.0670	LunarSAR Independent Location Probability	The Lunar Relay Service shall provide a probability of independent location (not relying on LunarSAR beacon-provided location data) of 95% within 10 minutes [TBR] of activation, for a LunarSAR beacon transmitting at 35 [TBR] dBm EIRP.				X	
LCRNS.3.0680	LunarSAR Independent Location Accuracy	The Lunar Relay Service shall locate an emergency beacon within the Lunar South Pole region with an accuracy of 50 meters [TBR], without reliance on the beacon's self-reported position for a LunarSAR beacon transmitting at 35 [TBR] dBm EIRP.				X	
LCRNS.3.0690	On-board self and built-in service testing	Each Lunar Relay service node shall have internal built-in test and verification capability.	X	X	X	X	

REQID	Requirement Name	Requirement Text	Effectivity				Table Ref
LCRNS.3.0700	Command Data Encryption	Each Lunar Relay service node shall use FIPS 140-3 certified encryption for all spacecraft commands.	X	X	X	X	
LCRNS.3.0710	Information System Authorization	The lunar relay providers ground system shall be assessed and authorized as a HIGH system in accordance with the Federal Information System Management Act of 2014 using NIST Special Publication 800-53, Revision 5.	X	X	X	X	
LCRNS.3.0720	Project Protection Plan	The lunar relay provider shall complete and update a Project Protection Plan (PPP) to identify known threats and response plans to mitigate associated risks.	X	X	X	X	
LCRNS.3.0730	Service Authentication	The lunar relay PNT service shall have the capability to provide authentication to users.	X	X	X	X	
LCRNS.3.0740	Service Availability Protection	The lunar relay system shall have anti-jamming capabilities to prevent denial of service via Radio Frequency Interference (RFI) or other electronic attack.				X	

Appendix B. User Mission Specific Information and Timeline Reference

B.1 User- Level Assumptions

Representative User-level assumptions are given throughout this document to help providers size their space and/or ground systems to include capabilities needed to meet requirements. This is needed since the specific missions are still in an evolutionary process, and any evolving details have the potential of leaving important capabilities out of the current requirements base. Specific details about each mission will be updated during the validation process.

B.2 Communications and Data Services Characteristics

For communication and data services, requirement 3.0370 and Table 3-6 Reference User System Performance and Data Rate Requirements provide the most current information on user communication characteristics.

B.3 PNT System Characteristics

Evolving over IOC increments and the EOC to meet the respective service volumes, the user will be able to receive and utilize several simultaneous AFS (1-way forward reference signals and associated messages) from different relay sources, which constitutes the Lunar Augmented Navigation System (LANS). The derived observables are used to estimate user Position, Velocity and Time (PVT). However, in IOC there may be a need for the user to supplement the set of observables from relay(s) with other data sources, such as DTE (Earth to lunar user), Inertial Measurement Unit, etc. The relays shall provide messages with all the information content related to the network that is required by the user to perform their PVT solution.

The user is expected to have the capability to receive signals from multiple relays simultaneously and process the metric tracking observables and message content to obtain a PVT solution.

B.4 User Timelines

This section provides an estimate of expected NASA user operational hours through a relay service in lunar space for IOC increments Alpha, Bravo, and Charlie. During Artemis missions, communication demand will also impact NASA's ability to provide DTE communication services to science missions. LNSP support will help "offload" NASA's DTE communication services via allocated LNSP lunar relay-Earth ground station assets.

In addition to Artemis, baseline support to lunar science missions is also anticipated. These science missions include Lunar orbiting and lunar surface missions to the Lunar south pole, and other locations including various locations near the lunar equator.

Tables B-1, B-2, and B-3 are based on assumptions that are expected to change as flight missions work through their concept of operations and later detailed flight operations over their development lifecycle. The purpose of this section is to provide insight on the current tentative picture of user demand anticipated for the LCRNS relay communication support.

Table B-1 IOC-A Mission Estimated Support

	Units[1]	Lunar mission class	Phase				
			Lunar orbit	**Descent**	**Surface**	**Ascent**	**Lunar orbit**
Mission Period	days		0 - 11	11 - 12	12 - 19	19 - 20	20 - 30
Duration	days		11	1	7	1	10
No. of contacts required per mission class	per day	Crewed Landing System[2]	5	9	9	9	5
		Robotic Orbiter/Landing[2]	5	3	3	3	5
		CubeSat or Small Payload[2]	5	3	3	3	5
No. of contacts across all mission classes	per day		15	15	15	15	15
Contact duration estimated[3]	hours		1				
Total contact time	hours per day		15	15	15	15	15
	hours per phase		165	15	105	15	150
Notes:							
[1] Whenever the term "day(s)" or "per day" is used, this refers to Earth days [2] For specific "lunar mission class" expected comm performance, see Table 3-6, Reference User System Performance and Data Rate Requirements and table 3-7 data volumes [3] Contact duration is just an estimation for the purpose of sizing and scoping, not the actual contact time expected							

Table B-2 IOC-B Mission Estimated Support

	Units[1]	Lunar mission class	Phase				
			Lunar orbit	Descent	Surface	Ascent	Lunar orbit
Mission Period	days		0 - 11	11 - 12	12 - 19	19 - 20	20 - 30
Duration	days		11	1	7	1	10
No. of contacts required per mission class	per day	Crewed Landing System[2]	6	15	15	15	6
		Robotic Orbiter/Landing[2]	6	3	3	3	6
		CubeSat or Small Payload[2]	6	4	4	4	6
No. of contacts across all mission classes	per day		18	22	22	22	18
Contact duration estimated[3]	hours		1				
Total contact time	hours per day		18	22	22	22	18
	hours per phase		198	22	154	22	180

Notes:

[1] Whenever the term "day(s)" or "per day" is used, this refers to Earth days
[2] For specific "lunar mission class" expected comm performance, see Table 3-6, Reference User System Performance and Data Rate Requirements and table 3-7 data volumes
[3] Contact duration is just an estimation for the purpose of sizing and scoping, not the actual contact time expected

Table B-3 IOC-C Mission Estimated Support

	Units[1]	Lunar mission class	Phase				
			Lunar orbit	Descent	Surface	Ascent	Lunar orbit
Mission Period	days		0 - 11	11 - 12	12 - 19	19 - 20	20 - 30
Duration	days		11	1	7	1	10
No. of contacts required per mission class	per day	Crewed Landing System[2]	18	24	24	24	18
		Crewed Surface Vehicle[2]	8	24	24	24	8
		CubeSat or Small Payload[2]	7	7	7	7	7
No. of contacts across all mission classes	per day		33	55	55	55	33
Contact duration estimated[3]	hours		1				
Total contact time	hours per day		33	55	55	55	33
	hours per phase		363	55	385	55	330

Notes:

[1] Whenever the term "day(s)" or "per day" is used, this refers to Earth days
[2] For specific "lunar mission class" expected comm performance, see Table 3-6, Reference User System Performance and Data Rate Requirements- and table 3-7 data volumes
[3] Contact duration is just an estimation for the purpose of sizing and scoping, not the actual contact time expected

Table B-4 is an estimate of the contact timeframe of activities for the lunar relay between non-crewed Artemis missions – this represents the set of nominal on-going activities needed to be supported by the relay for the 11 to 23 months (TBR) between each crewed Artemis mission provided above.

Table B-4 Non-Crewed Artemis Mission Estimated Support

	Units[1]	Lunar mission class	Phase				
			Operations				
Mission Period	days		330				
Duration	days		330				
No. of contacts required per mission class	per day	Quiescent Telemetry[2]	4				
		Robotic Orbiter/Landing[2]	4				
		CubeSat or Small Payload[2]	4				
No. of contacts across all mission classes	per day		12				
Contact duration estimated[3]	hours		1				
Total contact time	hours per day		12				
	hours per phase		3960	0	0	0	0
Notes:							
[1] Whenever the term "day(s)" or "per day" is used, this refers to Earth days [2] For specific "lunar mission class" expected comm performance, see Table 3-6, Reference User System Performance and Data Rate Requirements and Table 3-7 data volumes [3] Contact duration is just an estimation for the purpose of sizing and scoping, not the actual contact time expected							

B.5 Reference Trajectories for Descent and Ascent

Figure B-1 gives the NASA reference trajectory for an HLS landing on the lunar surface. Figure B-2 gives the reference ascent trajectory. These are given for specific dates and may be used to scope the dynamic service coverage for landing human systems.

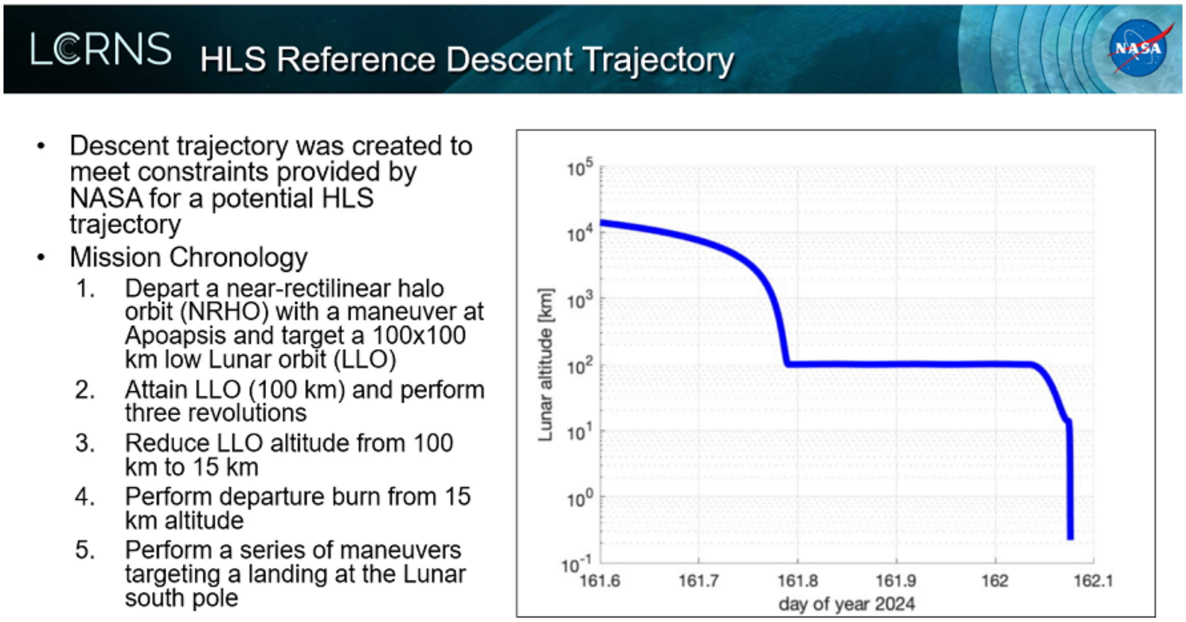

Figure B-1 Reference Trajectory for HLS Landing

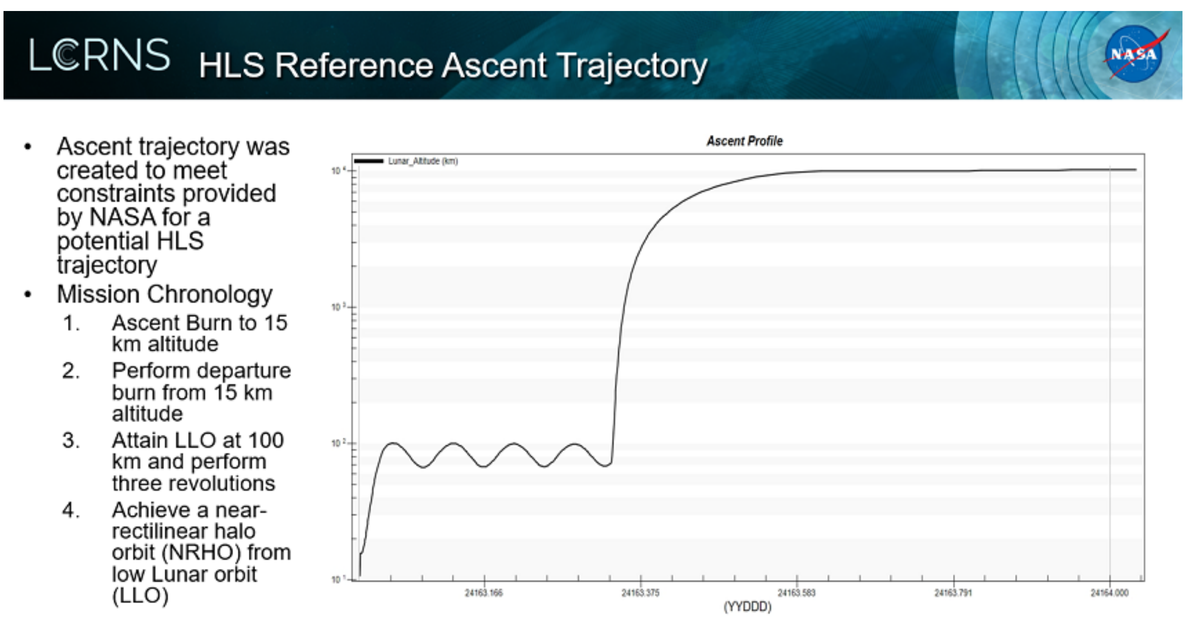

Figure B-2 Reference Trajectory for HLS Departure

Appendix C. LunaNet Interoperability Compliance Matrix

The table below is extracted from LNIS V4 Appendix A. This SRD requires compliance with those sections checked for IOC, Compliance to LunaNet Interoperability Specification EOC elements will be added as the specification evolves. Note that the LNIS also calls the EOC Phase as “sustaining.”

Table C-1 LCRNS SRD/LNIS Interoperability Specification Compliance Matrix for IOC

Section	Name	IOC
3.1.1.1	Real-Time Link Layer Communications Services	X
3.1.1.2	Real-Time Network Layer Communications Services	X
3.1.2	Store-and-Forward Communications Services	X
3.1.3	Messaging Services (Appendix D. LunaNet Application Messages, Table D-2. LANS / AFS Messages: PNT and Network Attributes)	X
3.1.3	Messaging Services (Appendix D. LunaNet Application Messages, Table D-2. LANS / AFS Messages: Detection and Network Communications)	
3.2.1.1	One-Way Doppler Reference (1wDRef)	X
3.2.1.2	Pseudo-Range and Timing Reference (1wRTRef)	X
3.2.1.3	Time-Transfer Reference (Tref)	X
3.2.2	Lunar Augmented Navigation System (LANS)	X
3.2.3.1	One-Way Doppler Measurement (1wDMeas)	
3.2.3.2	Pseudo-Range Measurement (1wRTMeas)	
3.2.4.1	Two-Way Doppler Measurement (2wDMeas)	X
3.2.4.2	Range Measurement (2wRMeas)	X
3.2.5.1	Two-Way Coherent Doppler Transponder (2wD-XPND)	
3.2.5.2	Non-Regenerative Range Transponder (2wNRR-XPND)	
3.2.5.3	Regenerative Range Transponder (2wRR-XPND)	
3.2.6	Supplemental Navigation Products (NavSupp)	X
3.2.7	Location Service (Loctn)	
3.3.1	Lunar Search and Rescue (LunaSAR) Services	
3.3.2	Space Weather Alerting Services	
3.4	Science Services	
3.5.1	Earth-based Scheduling Interface	X
3.5.2.1	Multiple Access Forward Link/Augmented Forward Signal (AFS) Service	X
3.5.2.2	Multiple Access Return Link	
3.5.2.3	User Initiated Services	
3.5.3	User Initiated Services	

Section	Name	IOC
4.1	LNSP-User Lunar Surface Interfaces	
4.2	LNSP-User Proximity Interfaces (PFS1a-c, PFS5, PRS1a-c, PFKa1, PRKa1)	X
4.2	LNSP-User Proximity Interfaces (All other interfaces except PFS1a-c, PFS5, PRS1a-c, PFKa1, PRKa1)	
4.3	LNSP-User DTE Interfaces (XU1, XD1, KaU1, KaD1)	X
4.3	LNSP-User DTE Interfaces (All other interfaces except XU1, XD1, KaU1, KaD1)	
4.4	LNSP-User Terrestrial Interfaces	X
5.1	LNSP A-LNSP B Communications Services	
5.2	LNSP A-LNSP B PNT Services	
6.1	LNSP A-LNSP B Lunar Surface Interfaces	
6.2	LNSP A-LNSP B Crosslink Interfaces	
6.3	LNSP A-LNSP B DTE Interfaces	
6.4	LNSP A-LNSP B Terrestrial Interfaces	

Appendix D. Glossary and Acronym List

Acronym	Description
ABC	Artemis Base Camp
AFS	Augmented Forward Signals
BER	Bit Error Rate
BPv7	Bundle Protocol version 7
CCB	Configuration Control Board
CCSDS	Consultative Committee for Space Data Systems
CDMA	Code Division Multiple Access
CLPS	Commercial Lunar Payload Services
DCN	Document Change Notice
DOF	Degree of Freedom
DOI	De-Orbit Insertion
DSN	Deep Space Network
DTE	Direct-To-Earth
DTN	Delay/Disruption Tolerant Networking
EIRP	Effective Isotropic Radiated Power
EOC	Enhanced Operating Capability
ESC	Exploration and Space Communications
FIPS	Federal Information Processing Standard
G/T	Gain-To-Noise Temperature Ratio
GDOP	Geometric Dilution of Precision
GPS	Global Positioning System
HLS	Human Landing System
ICSIS	International Communication System Interoperability Standard
IOC	Initial Operating Capability
IRD	Interface Requirements Document
ISRU	In-Situ Resource Utilization
LANS	Lunar Augmented Navigation System
LCRNS	Lunar Communications Relay and Navigation Systems
LEO	Low Earth Orbit
LHCP	Left Hand Circularly Polarized
LiDAR	Light Detection and Ranging
LLO	Low Lunar Orbit
LNIS	LunaNet Interoperability Specification
LNSP	LunaNet Service Provider
LTV	Lunar Terrain Vehicle

Acronym	Description
MISE	Measurement In Space Error
MAR	Multiple Access Return
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NSN	Near Space Network
P2P	Point-to-Point
PDI	Powered Descent Initiation
PNT	Position, Navigation, and Timing
PPP	Project Protection Plan
PR	Pseudo-range
PVT	Position, Velocity, and Time
QOS	Quality of Service
RHCP	Right Hand Circularly Polarized
RFI	Radio Frequency Inference
RF	Radio Frequency
SAR	Search and Rescue
SARSAT	Search and Rescue Satellite Aided Tracking
SCaN	Space Communications and Navigation
SISE	Signal In Space Error
SP	Service Provider
SRD	Services Requirements Document
SV	Service Volume
TBD	To-be Determined
TBR	To-be Refined
TBS	To-be Supplied