LunaNet Interoperability Specification Document

Draft Version 5

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APPENDIX TABLES:

LIST OF TO BE DETERMINED AND TO BE REFINED

The table below lists specific To Be Determined (TBD) and To Be Refined (TBR) items in the LNIS document. These items are yet to be finalized or currently undefined at the release of this version.

Each designator is numbered based on the document title, document version number when TBD/TBR was identified, parent section number, and number of the particular unresolved item. For example, "LNIS-TBD-6004" can be dissolved as – 4th unresolved TBD item identified in LunaNet Interoperability Specification Section 6. Once each item is dispositioned, the resolution will be substituted in place of the designator and the item will be struckthrough (~~LNIS-TBD-6004~~) in this table. If new unresolved items are identified, it will be added to this table using the above defined designation scheme. All TBD/TBR will retain its original numbers and will not be renumbered as items are added or deleted.

List of TBDs/TBRs

Designation	Section	Description
LNIS-TBD-3001	3.1.2 /Table 3: Bundle Protocol Service Interfaces	Applicable document needed for Bundles / TCPCL. Bundles are forwarded via TCP convergence layer adapter over TCP/IP.
LNIS-TBD-3002	3.1.2 /Table 3: Bundle Protocol Service Interfaces	Applicable document needed for Bundles / UDPCL - Bundles are forwarded via UDP convergence layer adapter over UDP/IP.
LNIS-TBD-3003 (incorporating LNIS-TBD-3004, LNIS-TBD-3005, and LNIS4-TBD-3006)	3.3 Messaging Services	Applicable document needed for Applicable document(s) needed for Messaging Services
LNIS-TBD-3007	3.2.1.2 Pseudo-Range and Timing Reference	Pseudo-noise (PN) codes as identified in CCSDS 414.1-B-2 and CCSDS 415.1-B-1 have traditionally been employed for two-way ranging purposes. To use them as an option for one-way measurements, a method (TBD) must be set in place to convey information to the user correlating source PN phasing and the corresponding time of transmission.
LNIS-TBD-3008	3.2.1.3 Time-Transfer Reference	A standardized method (TBD) for a LunaNet node to provide a time reference will be implemented to allow users to have accurate time.
LNIS-TBD-3009	3.2.4.2 Range Measurement	Frame ranging involves timestamping and identification of synchronized information frames. It is particularly useful in high-rate communications links, where elevated data frame rates facilitate more accurate time resolution. A frame ranging standard is TBD.

Designation	Section	Description
LNIS-TBD-3010	3.2.5.2 Non-Regenerative Range Transponder	In addition to what is performed for the two-way Doppler transponder service, a non-regenerative transponder filters and re-modulates the ranging signal onto the forward signal. The LNSP does not require knowledge of the ranging signal type employed by the user. The bandwidth allocated to the ranging signal and used by the LNSP for filtering shall be TBD.
LNIS-TBD-3011	3.2.6.1 Lunar Reference Frame	The use of a common lunar-centered, selenocentric reference frame across PNT services enables seamless consumption of the services, irrespective of specific LNSP or users. The lunar reference frame is described in detail in Lunar Reference Frame Standard (TBD).
LNIS-TBD-3012	3.2.6.2 Lunar Reference Time	The use of a common lunar reference time across LNSP infrastructure elements is required to enable synchronization of services and time in the lunar domain. This common lunar reference time is described in detail in Lunar Time System Standard (TBD).
LNIS-TBD-3013-1	3.4.1 Lunar Search and Rescue (LunaSAR) Services	The distress message might include the position of the beacon (if determined through the PNT services) or the beacon position might be computed by the LNSP (or another actor) via triangulation of the beacon as received by multiple LNSP nodes. A beacon might not know where the LNSP satellites are and might not have directive antenna capabilities, so the distress message might be broadcast and arrive at the LNSP with low power, this might require a dedicated, protected band, TBD.
LNIS-TBD-3013-2	3.4.2 Space Weather Alerting Services	Space Weather alerts and related messages will be communicated using the messaging services, per Appendix D. The specific standard alert and message content are still TBD.
LNIS-TBD-3014	3.6.2 User Initiated Services	The User Initiated Services (UIS) process may be executed through service acquisition protocols utilizing a combination of previously scheduled services or available interfaces. These options are detailed in section 3.6.2 and are still being determined.

Designation	Section	Description
LNIS-TBD-3015	3.6.5 Link Establishment	The standards for link establishment are TBD and will likely vary depending on whether the user is accessing a Single Access or Multiple Access LunaNet service.
LNIS-TBD-4001	4. Lunanet Service Provider To User Interfaces	Standards for optical link interfaces are TBD.
LNIS-TBD-4002	4.1 LNSP-User Lunar Surface Interfaces	LS3 - Short-to-medium range wireless network with mobility and roaming utilizing 3GPP rel. 16 (and higher) (LTE and 5G TBD).
LNIS-TBD-4003	4.1 LNSP-User Lunar Surface Interfaces	Target Frequency Range is TBD for LS3, Short-to-medium range wireless network with mobility and roaming.
LNIS-TBD-4004	Appendix B/ Table B-19 PFS2 - Proximity Forward S-band Medium Rate w/ Ranging	Proximity Forward S-band Medium Rate w/ Ranging (PFS2) 2025-2110 MHz - Fixed frequency assignments TBD.
LNIS-TBD-4005	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-19 PFS2 - Proximity Forward S-band Medium Rate w/ Ranging	Proximity Forward S-band Medium Rate w/ Ranging (PFS2) 2025-2110 MHz - Symbol & Chip Rates TBD.
LNIS-TBD-4006	Appendix B / Table B-20: PRS2 - Proximity Return S-Band Spread Spectrum	Proximity Return S-Band CDMA Return (PRS2) 2200-2290 MHz - Fixed frequency assignments TBD.
LNIS-TBD-4007	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-20: PRS2 - Proximity Return S-Band Spread Spectrum	Proximity Return S-Band CDMA Return (PRS2) 2200-2290 MHz - Symbol & Chip Rates TBD.
LNIS-TBD-4008	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-22: PRS5 - Proximity Return S-Band Multiple Access Return (MAR)	Proximity Return S-Band CDMA Return (PRS5) 2200-2290 MHz Fixed frequency assignments TBD.
LNIS-TBD-4009	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-22: PRS5 - Proximity Return S-Band Multiple Access Return (MAR)	Proximity Return S-Band CDMA Return (PRS5) 2200-2290 MHz Symbol & Chip Rates TBD.

Designation	Section	Description
LNIS-TBD-4010	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B /Table B-11: PFK1 - Proximity Forward K-band Data Only	Proximity Forward Ka-band Data Only (PFKa1) 23.15-23.55 GHz 1 Msps ≤ Rs ≤ TBD See Appendix B I.I Note [15]
LNIS-TBD-4011	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-12: PFK2 - Proximity Forward K-band Variable Coding and Modulation	Proximity Forward K-band Variable Coding and Modulation (PFK2) 23.15-23.55 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]
LNIS-TBD-4012	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-13: PFK3 - Proximity Forward K-band High-Rate Data Only	Proximity Forward K-band High-Rate Data Only (PFK3) 23.15-23.55 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]
LNIS-TBD-4013	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-14: PFK4 - Proximity Forward K-band High-Rate Data w/ Ranging	Proximity Forward K-band High-Rate Data w/ Ranging (PFK4) 23.15-23.55 GHz 1.5 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]
LNIS-TBD-4014	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-15: PRK1 - Proximity Return K-band Data Only	Proximity Return K-band Data Only (PRK1) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]
LNIS-TBD-4015	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-16: PRK2 - Proximity Return K-band Variable Coding and Modulation	Proximity Return K-band Variable Coding and Modulation (PRK2) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]
LNIS-TBD-4016	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-17: PRK3 - Proximity Return K-band High-Rate Data Only	Proximity Return K-band High-Rate Data Only (PRK3) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]
LNIS-TBD-4017	4.2 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-18: PRK4 - Proximity Return K-band High-Rate Data w/ Ranging	Proximity Return K-band Data w/ Ranging (PRK4) 27.0-27.5 GHz 1.5 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]

Designation	Section	Description
~~LNIS4-TBD-4018~~	~~[LNIS V4] 4.2 / Table 9 - Coding and Framing of Proximity Signals~~	~~PFS/PRS 1e coding is TBD~~ *Resolved, see Appendix B / Table B-5: PFS1e - Proximity Forward S-Band High Rate w/ Ranging, Table B-10: PRS1e - Proximity Return S-Band High Rate w/ Ranging*
~~LNIS4-TBD-4019~~	~~[LNIS V4] 4.2 / Table 9 - Coding and Framing of Proximity Signals~~	~~PFS/PRS 1e frequency and rate is TBD~~ *Resolved, see Appendix B / Table B-5: PFS1e - Proximity Forward S-Band High Rate w/ Ranging, Table B-10: PRS1e - Proximity Return S-Band High Rate w/ Ranging*
LNIS-TBD-4020	Appendix B / Table B-22: PRS5 - Proximity Return S-Band Multiple Access Return (MAR)	PRS5 Coding and Framing is TBD.
LNIS-TBD-4021	4.3/ Table 9: LNSP-User DWE signal interfaces, Appendix B / Table B-31: KU1 - K-band Uplink High Rate Data Only	K-band Uplink High Rate Data Only (KU1) Frequency Range & Symbol Rate - 22.55-23.15 GHz 2 Msps ≤ Rs ≤ 50 Msps (Upper Limit TBD)
LNIS-TBD-4022	4.3/ Table 9: LNSP-User DWE signal interfaces, Appendix B / Table B-32: KU2 - K-band Uplink High Data w/ Ranging	K-band Uplink High Rate Data Only (KU2) Frequency Range & Symbol Rate 22.55-23.15 GHz 2 Msps ≤ Rs ≤ 50 Msps (Upper Limit TBD)
LNIS-TBD-4023	4.3/ Table 9: LNSP-User DWE signal interfaces, Appendix B / Table B-33: KD1- K-band Downlink High Rate Data Only	K-band Downlink High Rate Data Only (KD1) 25.5-27.0 GHz2 Msps ≤ Rs ≤ 200 Msps [Upper Limit TBD], See Appendix B.ii Note [12]
LNIS-TBD-4024	4.3/ Table 9: LNSP-User DWE signal interfaces, Appendix B / Table B-34: KD2 - K-band Downlink High Data w/ Ranging	K-band Downlink High Data w/ Ranging (KD2)25.5-27.0 GHz 2 Msps ≤ Rs ≤ 200 Msps (Upper Limit TBD) See Appendix B.ii Note [12]
LNIS-TBD-4025	Appendix B / Signal Interface Descriptions	Applicable document for some signals are TBD. Standards development is an ongoing effort. See Appendix B.i.i Note [12], Appendix B.i.ii Note [6], Appendix B.ii Note [11], Appendix B.iii Note [7]
LNIS-TBD-6001	6.2 / Table 12 - LNSP–LNSP Crosslink Layer Interfaces	CFK1 Crosslink Forward Targeted Frequency Range is TBD 23.15 – 23.55 GHz (TBD)

Designation	Section	Description
LNIS-TBD-6002	6.2 / Table 12 - LNSP–LNSP Crosslink Layer Interfaces	CRK1 Crosslink Return Targeted Frequency Range is TBD 27.00 – 27.50 GHz (TBD)
LNIS-TBD-6003	6.2 / Table 12 - LNSP–LNSP Crosslink Layer Interfaces	CFK1 Crosslink Forward Applicable Documents to be determined.
LNIS-TBD-6004	6.2 / Table 12 - LNSP–LNSP Crosslink Layer Interfaces	CRK1 Crosslink Return Applicable Documents to be determinded.
~~LNIS-TBD-AD0001~~	~~Applicable Documents~~	~~[AD1] LunaNet and User Signal Structure Definition Document (TBD)~~
LNIS-TBD-AD0002	Applicable Documents	[AD2] LunaNet Measurement Schema and Parameters Document (TBD)
LNIS-TBD-AD0003	Applicable Documents	[AD3] LunaNet Detailed Message Definition Document (TBD)
LNIS-TBD-AD0004	Applicable Documents	[AD4] LunaNet Location Services for Users Document (TBD)
LNIS-TBD-AD0005	Applicable Documents	[AD5] Lunar Reference System and Lunar Time System Standard (TBD)
LNIS-TBD-AD0006	Applicable Documents	[AD6] Reserved for Future Use
LNIS-TBD-AD0007	Applicable Documents	[AD7] LunaNet LunaSAR Definition Document (TBD)
LNIS-TBD-AD0008	Applicable Documents	[AD8] LunaNet Interoperability Security Specifications (TBD)
LNIS-TBR-3001	3.4.1 Lunar Search and Rescue (LunaSAR) Services	LunaSAR's distress alert service is potentially received on PRS5 [TBR] and responded to over the PFS5 [TBR] links and are prioritized for rebroadcasting when received by the LNSP orbiting asset(s).
LNIS-TBR-4001	4.1 / Table 6 - LNSP–User Lunar Surface-Surface Link Layer Service Interfaces	For LS1 Short-range wireless network Targeted Frequency Range 5.150-5.835 GHz (Lunar Near-side use only) (TBR) under study.
~~LNIS-TBR-4002~~	~~[LNIS V4] 4.2 / Table 8 - LNSP–User Proximity Link Layer Service Interfaces]~~	~~Proximity Forward S-Band Medium Rate w/ Ranging (PFS1b) Chip rate TBR.~~ *Resolved, see Appendix B Table B-2: PFS1b - Proximity Forward S-Band Medium Rate w/ Ranging*

Designation	Section	Description
~~LNIS-TBR-4004~~	~~[LNIS V4] 4.2 / Table 8 - LNSP- User Proximity Link Layer Service Interfaces~~	~~Proximity Forward S-Band Low-Rate w/ Ranging (PFS1c)~~ ~~See Appendix B. See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM.~~ ~~TBR: supplemental reference for implementation of PN ranging.~~ ~~Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios).~~ *Resolved, see Appendix B Table B-3: PFS1c - Proximity Forward S-Band Low Rate w/ Ranging*
LNIS-TBR-4005	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-19: PFS2 - Proximity Forward S-band Medium Rate w/ Ranging	Proximity Forward S-band Medium Rate w/ Ranging (PFS2) SS-BPSK CDMA (~3Mcps) or SS-UQPSK TBR.
~~LNIS-TBR-4006~~	~~[LNIS V4] 4.2 / Table 8 - LNSP- User Proximity Link Layer Service Interfaces~~	~~Proximity Return S-Band Medium Rate w/ Ranging (PRS1b) Chip rate TBR~~ *Resolved, see Appendix B Table B-7: PRS1b - Proximity Return S-Band Medium Rate w/ Ranging*
~~LNIS-TBR-4007~~	~~[LNIS V4] 4.2 / Table 8 - LNSP- User Proximity Link Layer Service Interfaces~~	~~Proximity Return S-Band Medium Rate w/ Ranging (PRS1b)~~ ~~See Note [1]~~ ~~See CCSDS 401.0-B Section 2.2.7 for explanation of PCM/PM/bi-phase-L. TBR: supplemental reference for implementation of PN ranging.~~ *Resolved, see Appendix B Table B-7: PRS1b - Proximity Return S-Band Medium Rate w/ Ranging*
LNIS-TBR-4008	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-20: PRS2 - Proximity Return S-Band Spread Spectrum4	Proximity Return S-Band CDMA Return (PRS2) SS-SQPN TBR.

Designation	Section	Description
LNIS-TBR-4009	Appendix B / Table B-20: PRS2 - Proximity Return S-Band Spread Spectrum4	Proximity Return S-Band CDMA Return (PRS2) Intent is for a wide beam spread spectrum return intended for P2P links. Similar to PRS5 but allows for higher data rates (less spreading) and ranging. There is a possibility to support multiple users simultaneously, albeit much less than PRS5. Signal parameters could also be modified for user specific needs (TBR). See Appendix B.I.II Note [1].
LNIS-TBR-4010	4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-22: PRS5 - Proximity Return S-Band Multiple Access Return (MAR)	Proximity Return S-Band CDMA Return (PRS5) SS-BPSK CDMA (~3Mcps) or SS-UQPSK(Appendix C) TBR.
LNIS-TBR-4011	Appendix B / Table B-2: PFS1b - Proximity Forward S-Band Medium Rate w/ Ranging, Table B-7: PRS1b - Proximity Return S-Band Medium Rate w/ Ranging	PFS/PRS 1b uncoded is TBR
LNIS-TBR-4012	Appendix B / Table B-4: PFS1d - Proximity Forward S-Band High Rate Data Only, Table B-9: PRS1d - Proximity Return S-Band High Rate Data Only	PFS/PRS 1d uncoded is TBR
~~LNIS4-TBR-AP0001~~	~~Detailed Signal Definitions / Augmented Forward Signal Structure (PFS5)~~	~~To transmit a carrier center frequency of 2492.028 MHz, the reference clock can be at 1.023MHz utilizing a reference clock multiplier of 2436. The detailed definition of the signal is provided in LunaNet and User Signal Structure Definition Document [AD1]. The AFS data rate is expected to be between 250sps and 1ksps (TBR).~~

1 INTRODUCTION

LunaNet is envisioned as a network of cooperating networks (network of networks, akin to the terrestrial Internet) upon which providers can deliver communications, navigation, and other services for users on and around the Moon. LunaNet is based on a framework of mutually agreed-upon standards, protocols, and interface specifications that enable interoperability. LunaNet is intended to allow many lunar mission users to engage the services of diverse commercial and government service providers in an open and evolvable architecture. LunaNet Service Providers (LNSPs) can include communications, messaging, data transmission and distribution of position, navigation, timing, and situational awareness information. LunaNet can be implemented by LNSPs as part of the earliest missions and accommodate expansion as new users and service providers come online. Many nations, agencies, and private companies can contribute to and participate in the establishment and operation of LunaNet-compatible services. Just as the terrestrial Internet has public and private networks, LunaNet will have public and private networks. Private networks may be separated out by a combination of physical connectivity and/or policy and security implementations.

This document, along with its companion documents, provides the basis for a comprehensive set of specifications used by LNSPs. LunaNet elements will include Earth ground stations, orbiting spacecraft, and lunar surface systems, and will allow LNSPs to service a variety of missions including those for human exploration, lunar science, commercial applications, and space technology.

LunaNet will initially be instantiated by LNSPs comprised of a few nodes to meet the needs of early missions and evolve to meet the growing needs of a long-term lunar presence. All relay network services are not expected to be met by a single LunaNet-compatible spacecraft, or node. The expectation is that the needs of users will be met through a combination of interoperable commercial and government LNSPs. Interoperability across this network-of-networks can be achieved through negotiation of mutually-agreed-upon standards that will be reflected in this document and in the specifications defined by other participants in the cooperative LunaNet.

This current version of the document was written and reviewed by the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA).

1.1 PURPOSE

The purpose of this specification is to define the standards and interfaces for LNSPs to administer interoperable services to meet the needs of missions operating in the lunar vicinity. This document is not intended to replace either the International Communication System Interoperability Standards (ICSIS) or the Interagency Operations Advisory Group's (IOAG) Lunar Communications Architecture Documents. This document specifies a set of standards for services so that users may design their systems with the expectation of interoperability with multiple providers and users. Any individual provider is not required to offer all services and interfaces in this document, but the aggregation of providers will have the interfaces and services described. It is also possible for providers to offer services and interfaces beyond what is described in this document. However, those services and interfaces will likely not be interoperable between service providers, thereby limiting the service options for a user on or around the Moon.

This current document addresses all the LunaNet-compatible services, as currently identified. These services are expected to be met through a consortium of providers. To the extent that service providers follow the mutually-agreed-upon standards for the services and interfaces, which are reflected in this and applicable documents, the combined network can provide seamless services to multiple users.

The services and interfaces addressed in this document will be deployed by LNSPs over time. Development and procurement activities that lead to implementation are expected to have their requirements specifications that reference the specific sections within this document. The use of this document as the basis for the requirements will enable interoperability, while the development and procurement activities define the phasing of the implementations. Initial developments and procurements will focus on the requirements needed to support the early human exploration missions and other lunar missions with low lunar orbiters and landers at the South Pole and far side as primary locations of interest. The evolution toward a long-term capability will be aligned with the plans for the increased human and robotic lunar missions.

LunaNet compliance is defined at the service or interface level. That is, a service or interface is "LunaNet compliant" if it conforms to the appropriate specification within this document and the applicable documents.

1.2 SCOPE

This document defines the interoperable LunaNet standards and specifications for operations on the lunar surface and in cislunar space. International and commercial inputs are required to reach consensus on the contents of this document.

This document will provide the necessary guidance for LNSPs and users to design and build interoperable systems. These standards and specifications are intended for broad use by all parties operating in cislunar space and will be levied as requirements on systems and services required to be interoperable.

1.3 SECURITY CONSIDERATIONS

This section should be considered an informational reference as the LunaNet network continues to mature, and the national and international community further defines interoperable security requirements. A LunaNet Interoperability Security Specifications [AD8], referenced at the end of this section, will be the repository for detailed implementation specifications.

There are general expectations that users and providers shall protect the confidentiality, integrity, and availability of the systems, data, and communication pathways that will be part of LunaNet. These protections should be ensured using a combination of software and hardware that prevents unauthorized access, as well as corruption, interception, and loss of data. LNSP relays and nodes are also expected to have capabilities to enable rapid response to facilitate troubleshooting any communications anomalies.

United States National Institute of Standards and Technology (NIST) definitions for clarity:

- Confidentiality - Defined as preserving authorized restrictions on information access and disclosure, including ensuring the means for protecting personal privacy and proprietary information from access and disclosure.
- Integrity - Defined as guarding against improper information modification or destruction and includes ensuring information non-repudiation and authenticity.
- Availability - Defined as ensuring timely and reliable access to and use of information.

Users are expected to protect their data through encryption and authentication mechanisms appropriate to the type of data they are transmitting and/or receiving. All user protocols with security enhancements will be required to comply with communications standards outlined in this document and shall not result in architectural changes to LunaNet.

Network layer services, including but not limited to Internet Protocol (IP) and Bundle Protocol (BP), will be natively supported by LunaNet; this includes end-to-end data transport using IP security and BP security. All other data transport methods may be considered for approval with appropriate secure interfaces on a case-by-case basis for consideration and inclusion in the LunaNet Interoperability Specification.

Initially, the LunaNet infrastructure is likely to be implemented by LNSPs facilitating point-to-point (P2P) and broadcast links to specific sets of users. As a note, these users may make use of P2P and broadcast services from one or multiple LNSPs simultaneously. LunaNet is planned to evolve to incorporate a network based on a delay/disruption tolerant networking (DTN) with several LNSPs operating with cross-links between relays and creating multiple data flow paths. In the evolved DTN configuration, LNSPs will require jointly agreed DTN management and service orchestration policies to cover additional aspects such as bundle lifetimes, validity of routes, quality of service/prioritization, and network security management protocols. The administration and management of such a network in a secure manner will require Interconnection Security Agreements between LNSPs and associated space agencies/administering bodies in accordance with Consultative Committee on Space Data Standards (CCSDS) 350.4-G-2 Annex A.

LunaNet Interoperability Security Specifications [AD8] is under development. Once approved, this will be the authoritative source for interoperable LunaNet security requirements.

1.4 APPLICABLE DOCUMENTS

[AD1] LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LNIS-TBD-AD0001)
[AD2] LunaNet Measurement Schema and Parameters Document (LNIS-TBD-AD0002)
[AD3] LunaNet Detailed Message Definition Document (LNIS-TBD-AD0003)
[AD4] LunaNet Location Services for Users Document (LNIS-TBD-AD0004)
[AD5] Lunar Reference System and Lunar Time System Standard (LNIS-TBD-AD0005)
[AD6] Reserved for Future Use
[AD7] LunaNet LunaSAR Definition Document (LNIS-TBD-AD0007)
[AD8] LunaNet Interoperability Security Specifications (LNIS-TBD-AD0008)

Other relevant documents:

CCSDS 702.1-B-1
CCSDS 734.1-B-1
CCSDS 133.1-B-3
CCSDS 414.1-B-2
CCSDS 415.1-B-1
CCSDS 911.1-B-4
CCSDS 911.2-B-3
CCSDS 912.1-B-4
CCSDS 922.3-R-1
CCSDS 732.1-B-2
CCSDS 231.0-B-4
CCSDS 401.0-B-31
CCSDS 131.0-B-3
CCSDS 231.0-B-4

2 LUNANET INTEROPERABILITY OVERVIEW

LNSPs provide interoperable communications and navigation - or position, navigation, and timing (PNT) - services to user systems on and around the Moon. The Moon-based systems are referred to as the User Lunar Segment, and the users' associated systems on Earth are referred to as the User Earth Segment. As seen in Figure 1, LunaNet has a Lunar Segment and an Earth Segment. The Lunar Segment contains elements that could either be in lunar orbit or on the lunar surface. Though they may be referred to in general as "lunar relays," it is possible that some elements of the Lunar Segment may not provide any communications relay functions but support PNT or other non-data relay functions.

The User Lunar Segment may interface with LunaNet by either a connection with an LNSP Lunar Segment or with the LNSP Earth Segment, or both. The LNSP Earth Segment is comprised of ground stations on Earth, possible Earth orbiting relays, and associated operations centers. Note that there are also interfaces between the LNSP Lunar Segment and the LNSP Earth Segment, these may be either intra-network, i.e., within a network provided by a single provider, or it may be inter-network, i.e., between cooperating providers. Standardization of the LNSP Lunar Relay-Earth Interface will enable the inter-network or cross support of lunar relay services by multiple providers. The LNSP Lunar Relay-Earth Interface, shown in Figure 1, is an intra-network example where a single provider in this case may use a non-standardized interface. The LNSP Lunar Relay-User Interface and LNSP -Direct-with-Earth Interface are standardized. The interface between the LunaNet Earth Segment and the User Earth Segment will also be standardized. Note that the user could provide a private direct link between its lunar and Earth segments. This is outside the scope of LunaNet interoperability and is not addressed in this specification.

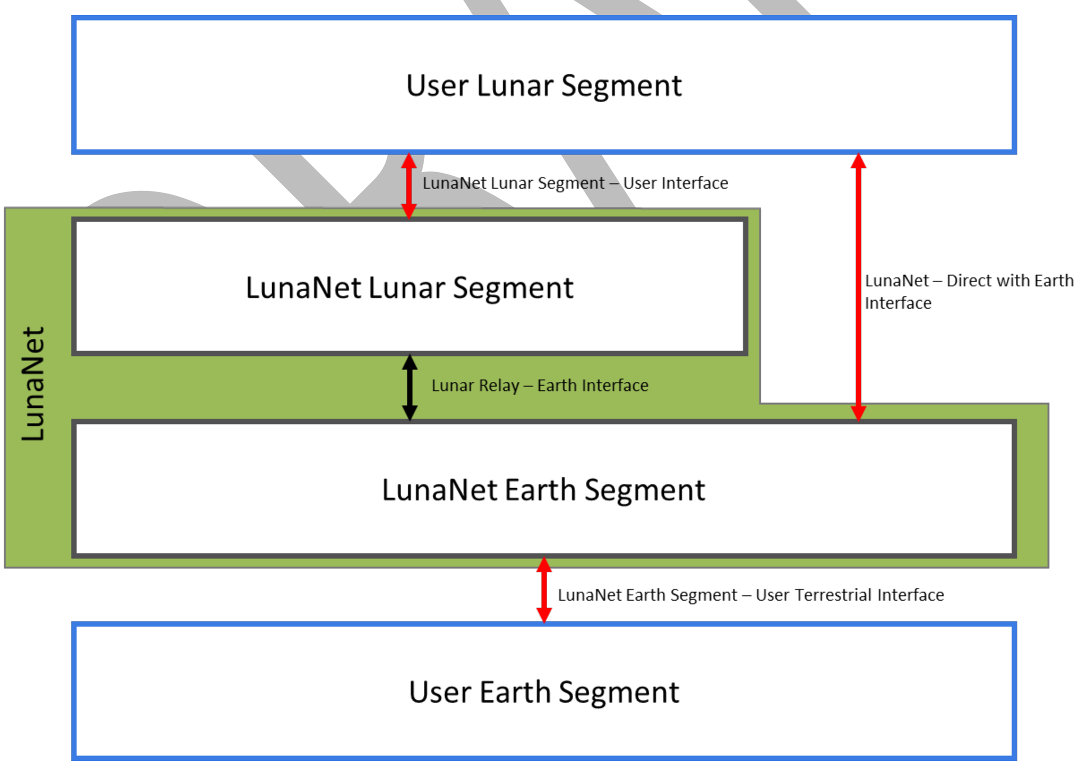

Figure 1: LunaNet Segments

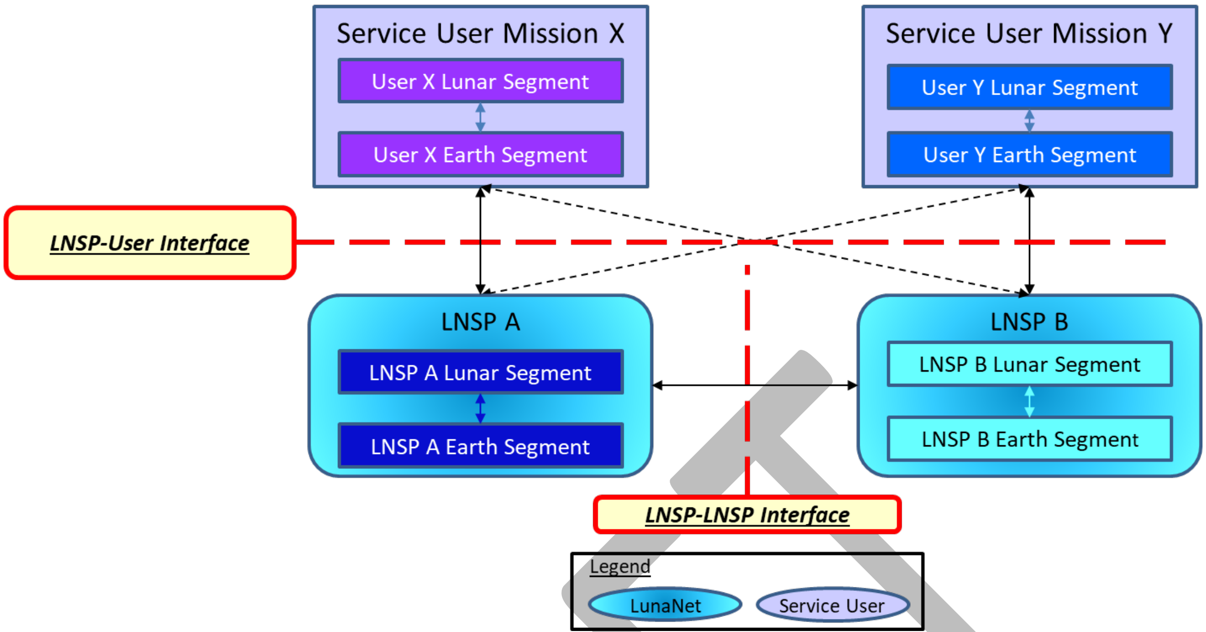

Figure 2: LunaNet Standard Services and Interfaces between LNSPs and Users

Like the terrestrial internet, LunaNet will be built up through multiple LNSPs combined to provide services to users. To allow users to receive those services from any provider such that it appears as a single provider to that individual user, two categories of interoperable interfaces are required. See Figure 2.

The first category is the LNSP-User Interface, which includes the service interfaces between a user and a provider. These include both the physical interfaces and the protocols and messages that provide services over those interfaces. A user shall be able to operationally receive the same service from different providers in the same way, such that the user will be able to use any connection as a LunaNet access point. Section 3 of this document describes the User Services and section 4 covers the LNSP to User Interfaces.

The second category is the LNSP – LNSP Interface. These include the physical interfaces and the protocols and messages that allow different LNSPs to work together to create the larger LunaNet infrastructure by augmenting individual LNSP capabilities with LNSP partners. Section 5 of this document describes the LNSP-to-LNSP Services and section 6 covers the LNSP-to-LNSP Interfaces.

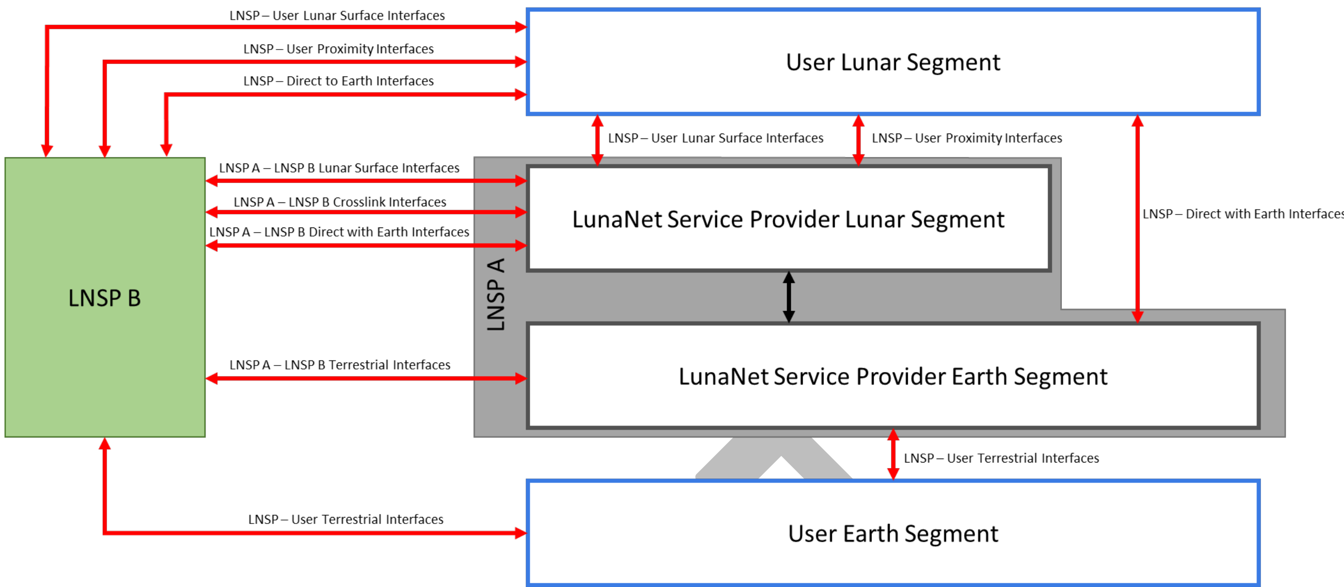

Figure 3: LunaNet Service Providers Interfaces

The LNSP interfaces are depicted in Figure 3. Each LNSP may have any combination of lunar surface, proximity, direct with Earth (DWE), and terrestrial interfaces with users. Interfaces between LNSPs may be any combination of lunar surface, crosslink, direct-with-Earth, and terrestrial interfaces. Lunar surface interfaces are interfaces between an LNSP lunar surface node and a user surface node. Proximity interfaces are between an LNSP lunar orbiting node and an orbiting or surface node. Note that the terms Direct-with-Earth (DWE) and Direct-to-Earth (DTE) are considered synonymous in this document. DWE will be used in order to avoid ambiguity about directionality. This document identifies the standards to be used for the physical and service interfaces described above and depicted in red in Figure 3.

Table 1: Lunar Network Service Provider Interfaces

Interface Name	Interface Description	Document Section
LNSP-User Lunar Surface Interfaces	Surface to surface interfaces between user and provider	4.1
LNSP-User Proximity RF Interfaces	User interfaces with lunar orbiting provider nodes	4.2
LNSP-User DWE RF Interfaces	Interfaces between user lunar systems and provider Earth systems	4.3
LNSP-User Contingency RF Interfaces	Very low data rate proximity and DWE interfaces for contingency operations	4.4
LNSP-User Terrestrial Interfaces	Terrestrial interfaces between user and provider	4.5
LNSP A-LNSP B Lunar Surface Interfaces	Surface to surface interfaces between two LNSPs	6.1
LNSP A-LNSP B Crosslink Interfaces	Interfaces between two LNSPs lunar orbiting nodes	6.2

Interface Name	Interface Description	Document Section
LNSP A-LNSP B DWE Interfaces	Interfaces between an LNSP lunar system and a different LNSP earth system	6.3
LNSP A-LNSP B Terrestrial Interfaces	Terrestrial interfaces between two LNSPs	6.4

3 USER SERVICES

3.1 COMMUNICATIONS SERVICES

There are two communications service types. See Figure 4. Note that the service between and a source and destination may be provided by multiple nodes between the source and the destination.

1. Real-time data services provide end-to-end data delivery between a source and destination with minimal delay. The latency on these services will be due to the signal travel time, any channel coding, and data operations only.

2. Store-and-forward data services provide end-to-end data delivery with additional latency incurred by storage of data along the end-to-end path. This storage allows for the delivery of data when discontinuities or significant rate buffering occurs along the path.

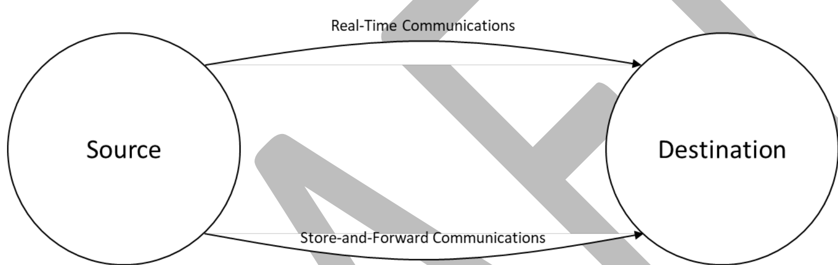

Figure 4: Two Types of Communications Services

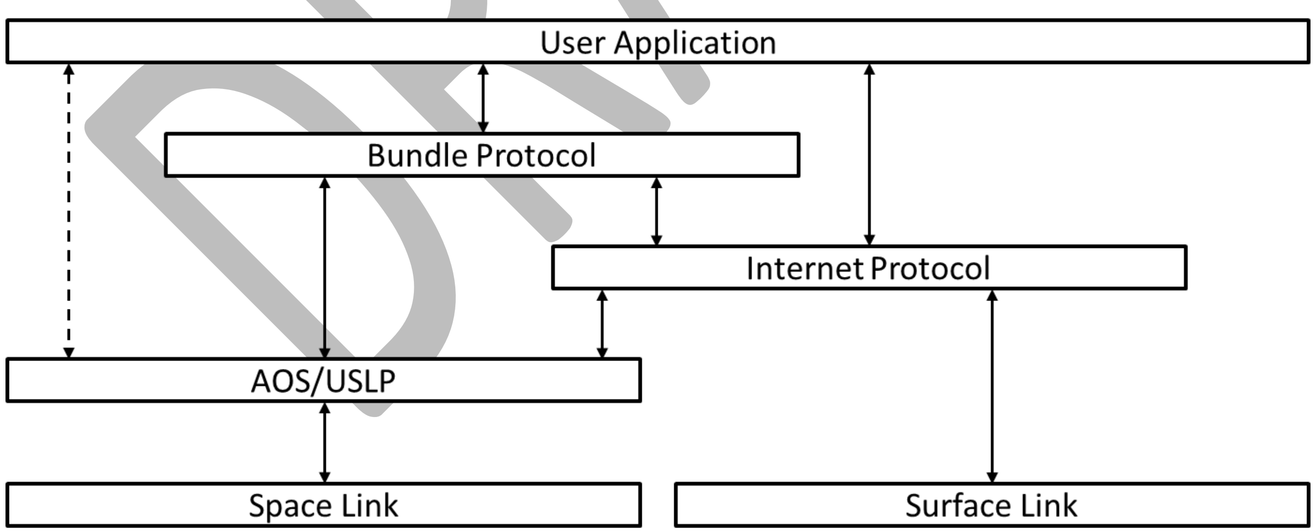

Figure 5: User Application Simplified Protocol Stack

Figure 5 is a simplified view of the protocol stack options for LunaNet user applications. Note that this is a simplified view and intentionally does not include the full stack to streamline introductory discussions. The applications are expected to be network-based using either the DTN BP or IP. However, a user application may use link layer services (dashed line) using the CCSDS Advanced Orbiting Systems (AOS) and USLP standards. The direct use of link layer services is intended for messaging services for LunaNet protocols only and should be discouraged for user applications. Connections to a LunaNet access point over any available link will allow the user's data to route to its destination. Though LunaNet permits link layer services, network-based applications will allow for the evolution and scalability of both user and provider systems.

3.1.1 REAL-TIME COMMUNICATIONS SERVICES

Real-time communications services may be provided at both the link layer and the network layer.

3.1.1.1 REAL-TIME LINK LAYER COMMUNICATIONS SERVICES

Link layer services will allow the relaying of data at the frame level and requires no processing of user data within those frames. This may be required due to user link layer security or to enable higher speed operations. The link layer service may include the multiplexing, de-multiplexing, and forwarding of user data frames.

For interoperability, the link layer services will initially require CCSDS AOS frames. Future transition to variable length frame standard is planned to simplify multiplexing and de-multiplexing data frames for users having different frame lengths because AOS frames are fixed length. CCSDS Unified Space Data Link Protocol (USLP) has been included in this document with the intent to transition from AOS to USLP. AOS will continue to be supported. End-to-end delivery of data over a series of multiple links using link layer services will require pre-configuration of the full end-to-end path and is subject to interruption due to unplanned events.

3.1.1.2 REAL-TIME NETWORK LAYER COMMUNICATIONS SERVICES

Real-time network layer services provide end-to-end delivery of data over a series of multiple links with increased functionality and flexibility over the link layer services. The only network layer service guaranteed to provide end-to-end delivery to any network user is the DTN BP. However, operation assumptions for specific user applications will allow successful application support through real-time network layer services provided using the IP. Use of IP requires both the source and destination to be operating within a portion of the network capable of supporting IP, such as the lunar surface. IP services are provided over AOS frames and USLP on the links described above or commercial standards, such as local wireless systems. Table 2 below provides a summary of the IP service interfaces. Since DTN BP also provides the store-and-forward communications services, the interfaces for BP services are described in Table 3 in the following section.

Table 2: IP Service Interfaces

Interface Name	Description	Applicable Interfaces	Applicable Documents
IP over CCSDS Encap/AOS	IP packets encapsulated using CCSDS encapsulation service and inserted into AOS frames	All AOS link layer service interfaces	CCSDS 702.1-B-1

Interface Name	Description	Applicable Interfaces	Applicable Documents
IP over CCSDS Encap/USLP	IP packets encapsulated using CCSDS encapsulation service and inserted into AOS frames	All USLP link layer service interfaces	CCSDS 702.1-B-1
IETF Standards	IP packets over current terrestrial standards	All terrestrial standard-based interfaces	

3.1.2 STORE-AND-FORWARD COMMUNICATIONS SERVICES

Interoperable store-and-forward communications services will be provided by DTN BP. In situations where DTN nodes are connected via an IP network, lunar surface networks, terrestrial networks, and/or on-board networks, the DTN bundles can be carried via Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) convergence layer protocols over standard terrestrial internet protocols (see section 223.1.1.2). For those cases where no direct IP connection is available or not suitable due to the link characteristics, the DTN data bundles are carried by either a Licklider Transmission Protocol (LTP) convergence layer with LTP segments encapsulated in encapsulation packets or directly in encapsulation packets, which will be carried over an AOS or USLP link layer (see section 3.1.1.1). Table 3 below provides a summary of these options.

Table 3: Bundle Protocol Service Interfaces

Interface Name	Description	Applicable Documents
Bundles / TCPCL	Bundles are forwarded via TCP convergence layer adapter over TCP/IP	LNIS-TBD-3001
Bundles / UDPCL	Bundles are forwarded via UDP convergence layer adapter over UDP/IP	LNIS-TBD-3002
Bundles / LTPCL	Bundles are forwarded via LTP convergence layer adapter over Encapsulation Packet Protocol	CCSDS 734.1-B-1 CCSDS 133.1-B-3
Bundles / EPPCL	Bundles are forwarded via EPP convergence layer adapter over Encapsulation Packet Protocol	CCSDS 133.1-B-3

3.2 POSITION, NAVIGATION, AND TIMING SERVICES

PNT services enable missions to determine position, velocity, or surface location, plan trajectories, execute maneuvers, and maintain accurate time with 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 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 LunaNet nodes, this will establish a Lunar Augmented Navigation System (LANS) as described in section 3.2.2, leading to a Global Navigation Satellite System (GNSS)-like capability for lunar PNT services. Similar to GNSS, a Code Division Multiple Access (CDMA) signal structure will be used for the AFS communications link and can also be applied to dedicated proximity links.

For communications links other than CDMA with a known transmit frequency, the receiver could measure the Doppler shift on the carrier. Non-CDMA links supported by pseudo-noise (PN) codes could provide an alternate method to derive pseudo-range measurements beyond the traditional two-way methods with ground source and measurement. In addition, a method whereby a specific data frame at an integer modulo 1-second based on an accurate and stable time reference source can be used to provide pseudo-range and time-transfer capability on these links.

For full interoperability, additional specifications will be developed as follows:

1. LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal [AD1]
2. LunaNet Measurement Schema and Parameters Document [AD2]
3. LunaNet Detailed Message Definition Document [AD3]
4. LunaNet Location Services for Users Document [AD4]
5. Lunar Reference System and Lunar Time System Standard [AD5]

For effective interoperability in the PNT domain, the signal structures for LNSPs and users must be defined [AD1], along with the implementation schemas for measurements [AD2] and lunar reference systems [AD5] for obtaining the measurements to ensure consistency in performance.

Appendix D identifies the PNT services and associated messages required for interoperability. The specific service identifications are explained in the subsections of 3.2. The specifics of the messages will be defined in standard protocols used as part of the provision of the services [AD3]. Interoperability also relies on defining the formats and contents; transmission periodicity, cadence, and latency; and prioritization for the messages for each signal type and service.

All PNT services described in sections 3.2.1 through 3.2.5 require the LNSP to have knowledge of the position, velocity, and timing (PVT) of its own relay satellites, as well as future predicted values. This information is required to be forwarded to users for the consumption of the related services, in the form of messages MSG-G4 and MSG-G5. Appendix D identifies additional messages that can be used to inform a comprehensive state of LNSP node(s) or a user.

The PNT services can be grouped into two categories, as shown in Figure 6:

1. Dedicated Links: This group of services include all the options described in the following sections that are not broadcast in 2483.5-2500 Megahertz (MHz). These services are expected to be provided by direct links between the user and the provider. Not all links will provide all the services described in sections 3.2.1 and 3.2.3 - 3.2.5. A dedicated 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.

2. Lunar Augmented Navigation System (LANS): This service is provided from multiple provider nodes to multiple users at the same time, as described in section 3.2.2. The concept is similar to GNSS. This service is provided in 2483.5-2500MHz band via the AFS using the PFS5 signal. This service is expected to be provided with relatively large field-of-view antennas to cover a large part of the service volume with the same signal. The service will be composed of a collection of LNSP nodes aimed at achieving global lunar coverage of a minimum of four simultaneous LANS nodes in view at any given time. Users employing omnidirectional or hemispherical antennas can therefore receive signals from multiple LunaNet nodes simultaneously. It should be noted that LANS can also be implemented over a select (local) lunar region (e.g., South Pole), if the right number of vehicles (nodes) are in view at any given time.

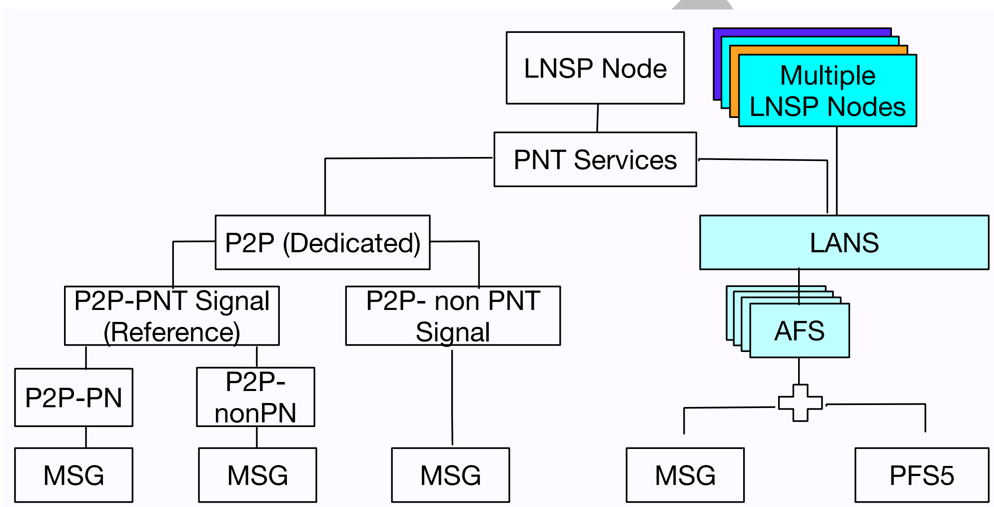

Figure 6: PNT Services Provided by LNSP

The following sections define and describe the services available from reference signals, including the special case of LANS. Then the concept of measurement services is introduced, followed by transponder, supplemental, and finally, location services. The figures in these sections use an arrow to indicate the directionality associated with the notional image of a signal path.

3.2.1 REFERENCE SIGNALS

LunaNet reference signals originate from an LNSP node, as depicted in Figure 7. These reference signals offer users the opportunity to derive measurements which describe the relative dynamics of the link between the LNSP reference source and the recipient. Defining the properties of each reference signal source enables users to derive pseudo-range, timing, and one-way Doppler observables through their receiver system.

Note: While a signal similar to a LunaNet reference signal may be initiated by a user, for clarity this user-originating signal is not defined as a reference signal. Instead, the concept of a "one-way measurement service" is introduced in section 3.2.3. If a user transponds an LNSP reference signal, the LNSP node offers a "two-way measurement service" on that returned link as described in section 3.2.4.

A combination of one-way observables and related messages from different LunaNet-compatible sources are utilized by a user's in-situ navigation system to estimate the user's PVT. A user may elect to complement LunaNet observations with other measurement types, but those are not addressed in this document.

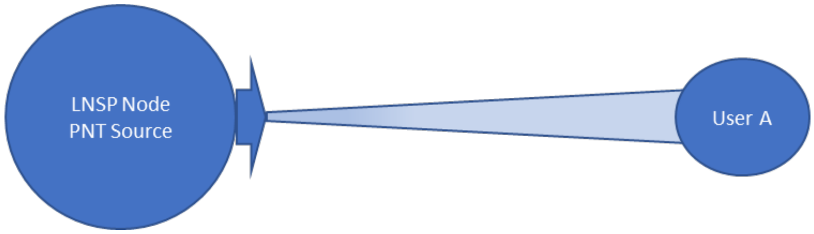

Figure 7: Reference PNT Signals Provided by an LNSP Node

3.2.1.1 ONE-WAY DOPPLER REFERENCE

Most radio frequency communications links may be employed for the purposes of obtaining one-way Doppler measurements by a user, provided the user has accurate knowledge of the center frequency employed by the source. This is best accomplished with the use of a fixed frequency transmission.

Differences in the measured frequency by the user will be due to Doppler, as well as frequency offsets from both LunaNet and user's frequency oscillator sources. The LNSP source conveys reference frequency value and deviations via a message, as identified in Appendix D.

3.2.1.2 PSEUDO-RANGE AND TIMING REFERENCE

The pseudo-range measurement approximates the distance between a LNSP source and the user's receiver. The source emits a recognizable pattern at a given instant in time, which the user receives moments later, identifies, and timestamps. The delay measurement represents a one-way time of flight.

Depending on the characteristics of the communications link, these patterns will take the form of Pseudo-noise (PN) sequences or high-rate frame synchronization and identification (i.e., frame ranging). Frame ranging is the term used in this document to refer to "telecommand/telemetry ranging," with the telemetry ranging as defined in [RD24], and telecommand ranging definition proposed in [RD25]. While the latter is currently a work in progress, PN sequences have been employed in satellite ranging technologies for quite some time. PN codes as identified in CCSDS 414.1-B-2 and CCSDS 415.1-B-1 have traditionally been employed for two-way ranging purposes. To use them as an option for one-way measurements, a method (LNIS-TBD-3007) must be set in place to convey information to the user correlating source PN phasing and the corresponding time of transmission. Signal structures like those utilized in Earth's GNSS, such as PFS5 links described later in this document, include PN sequences that repeat an integer number of times each second. This establishes a simple method for the LNSP source to inform users of PN phasing and timing information to form a pseudo-range observation.

Pseudo-range measurements will include errors due to source and receiver time offsets, unaccounted equipment delays on both ends, and time dilation effects. Information concerning errors originating from the LNSP source is provided to users via messages as identified in the tables in Appendix D.

3.2.1.3 TIME-TRANSFER REFERENCE

A standardized method for a LNPS node to provide a time reference will be implemented to allow users to have accurate time. This is currently being developed in LNIS-TBD-3008.

3.2.2 LUNAR AUGMENTED NAVIGATION SYSTEM (LANS)

The AFS is a special case instantiation of the reference signals described in section 3.2.1. The compatible LNSP nodes will transmit the AFS, as described in section 3.6.4.1 and Appendix C, in the 2483.5-2500

MHz band (PFS5). A collection of LNSP nodes transmitting the AFS constitutes the LANS, which is illustrated in Figure 8.

LNSP nodes broadcasting AFS shall be synchronized among themselves and against a common reference time scale. Frequency offsets will be estimated against the reference by each provider. The user computes the time of arrival and frequency of the received CDMA signal by using the information provided in the broadcast navigation messages (e.g., ephemeris, clock corrections, and time and frequency information) to compute a pseudo-range, Doppler shift, and carrier phase. Considering the collection of observables from different LNSP nodes and the correlated broadcast navigation messages, the user can autonomously compute its position/velocity and the difference between the local receiver clock and the LNSP system reference clock. Appendix D contains the mapping of messages to the LANS via the AFS.

As with all other PNT services, a common lunar-centric reference frame and time system is defined per section 3.2.6. Each LNSP shall ensure they either implement these reference systems directly (e.g., signals are synchronized with the lunar reference time and the lunar reference frame with associated geodetic system components is used in the navigation products) or provide sufficient information to the user in the broadcast navigation messages to refer to these common reference systems (e.g., broadcast of the time offset of the specific LNSP time to the lunar reference time).

Like GNSS, the LANS service will allow the user to compute code pseudo-ranges and carrier phase measurements from the AFS. Each LNSP shall ensure the AFS is provided with signal-in-space-error (SISE) within the maximum values specified in Appendix C, which allows users to derive reliable navigation solutions at a dependable level based on AFS signals from multiple LNSPs.

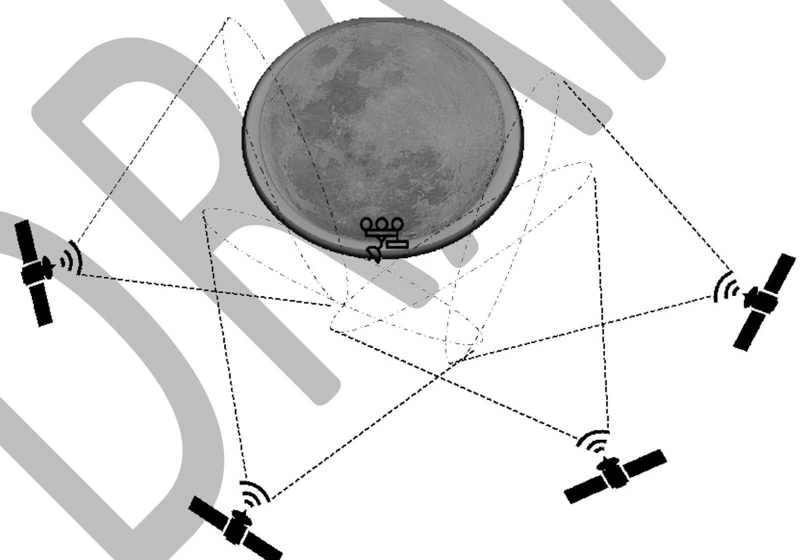

Figure 8: LANS PNT Concept Provided by LunaNet Nodes

The LANS via AFS is a multiple access forward link and allows reception by multiple users from the same LNSP node (one-to-many). Additionally, it also supports a many-to-one concept (i.e., GNSS-like with AFS signals from multiple LNSP nodes received by one user) owing to the mandatory time synchronization of the nodes, the coordinated generation of PNT-specific navigation messages, and the CDMA differentiation among the LNSP nodes. Further details about the AFS and the PFS5 signal structure are provided in Appendix C.

The full LANS service volume, depicted in Figure 9, identifies the minimum global lunar space volume in which LANS services will be provided and performance must be met. However, an evolutionary approach is anticipated to build toward the full-service volume, with an expected start over the South Pole of the Moon. This is notionally shown in Figure 10 below.

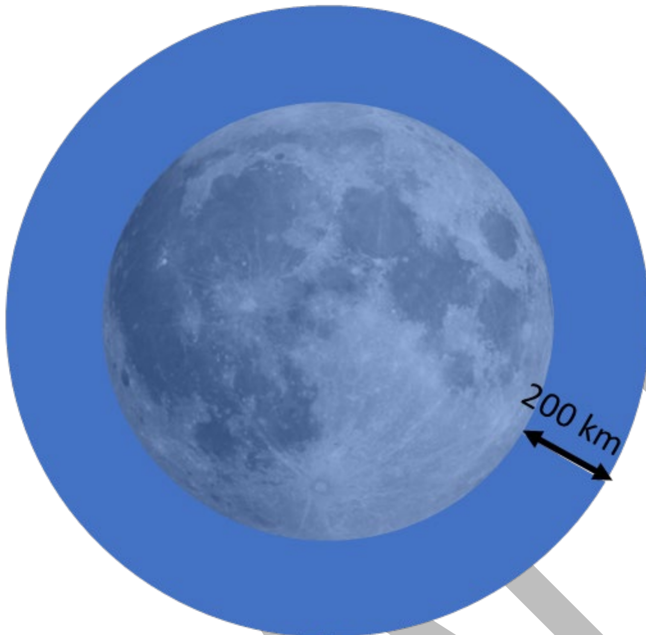

Figure 9: LANS Full-Service Coverage and Performance Volume

The LANS full-service volume includes lunar surface areas for all latitudes and altitudes out to a minimum of 200 kilometers above the surface for global coverage of the Moon.

Figure 10: Notional LANS South Pole Service Coverage and Performance Volume

3.2.3 ONE-WAY MEASUREMENTS

One-way measurements performed by LNSP nodes are in reverse fashion to what is described in section 3.2.1 and explained herein and depicted in Figure 11. The users generate signals similar to the construct of a LNSP-transmitted reference signal, so that they enable LNSP nodes to compute one-way Doppler and pseudo-range observables from the user. The resulting one-way measurement observables are forwarded to the necessary element via MSG-G13 messages, as identified in Appendix D.

Note: A navigation system may elect to complement LNSP observations with other measurement types, but those are not addressed in this document.

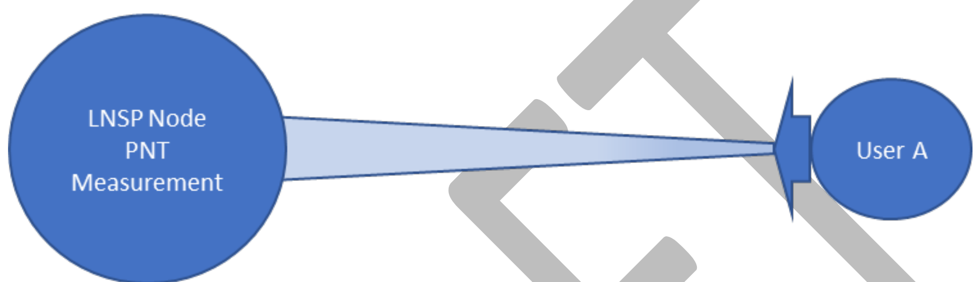

Figure 11: One-Way Measurements Performed by a LNSP Node

3.2.3.1 ONE-WAY DOPPLER MEASUREMENT

One-way Doppler measurements may be carried out for most incoming radio communications signals by tracking the frequency of the received signal and reporting the delta with respect to a defined source frequency. These measurements become valuable when the original frequency transmitted by the user is known. The quality of the measurement will depend on the stability of the user's frequency source, as well as the signal-to-noise ratios of the received signal. Errors due to frequency offsets between user and LNSP frequency references may be estimated by the corresponding navigation system. Users employ messages, as identified in Appendix D, to convey their transmitted frequency values and deviations.

3.2.3.2 PSEUDO-RANGE MEASUREMENT

The pseudo-range measurement is as described in section 3.2.1.2, though for a measurement concept the user generates the constructed signal that is utilized by the measuring LNSP system to obtain a pseudo-range observable. The LNSP system must be compatible with, and knowledgeable of, the ranging signal characteristics employed by the user as indicated in the LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal [AD1] interoperability specification.

Pseudo-range measurements will include errors due to source and receiver time reference offsets, and unaccounted phase delays and time corrections beyond what can be determined. The LNSP measurement system interprets information concerning these errors originating on the user end via user-provided messages, as indicated in Appendix D: MSG-G4. LNSP measurement systems are to be included in the corresponding observation messages, as indicated in Appendix D: MSG-G13.

3.2.4 TWO-WAY MEASUREMENTS

Two-way measurements performed by LNSPs are similar to two-way radiometric services historically provided by the different tracking networks, such as the Near Space Network or Deep Space Network, where the tracking stations compare the transmitted and received signals to derive observations of round-trip Doppler and range in terms of time-of-flight delay. In the current scenario, the LNSP node originates the transmit signal. These measurements require users to return a signal that is coherently related to the signal they received from the LNSP node, as illustrated in Figure 12 below. Range measurements can be supported by non-coherent, two-way communication interfaces by means of frame ranging as described in section 3.2.4.2 below.

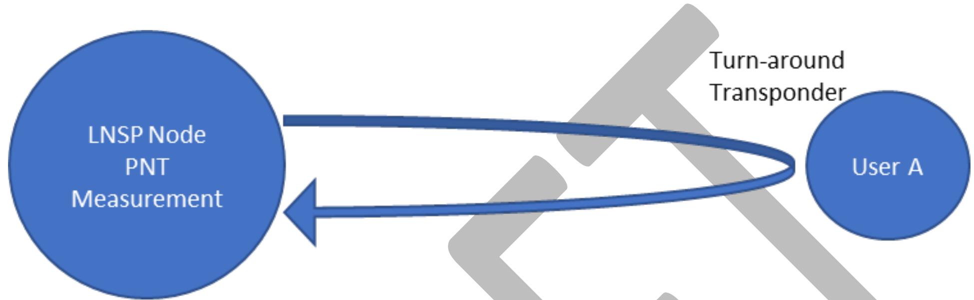

Figure 12: Two-Way Measurements Performed by LNSP Node

Two-way measurement observations are disseminated to the required element via MSG-G13 messages, as indicated in Appendix D.

3.2.4.1 TWO-WAY DOPPLER MEASUREMENT

Two-way Doppler measurements require an LNSP to determine the differences in phase between transmitted and received signal center frequencies at predetermined time intervals. The user must coherently transpond the received frequency from LunaNet by implementing a predefined turn-around ratio.

3.2.4.2 RANGE MEASUREMENT

The range measurements performed by LNSPs can be separated into three categories: non-regenerative, regenerative, and frame ranging. Non-regenerative ranging, or transparent ranging, involves the user filtering and re-modulating the ranging signal onto the return signal. This method does not require the user to have prior knowledge of the ranging signal utilized for the service, only the frequency bandwidth allocated to it. The PN ranging signals described in CCSDS 414.1-B-2 may be used for this purpose. Regenerative ranging involves PN code acquisition by the user and the return of a synchronized return PN ranging signal. It reduces the amount of noise present in the measurement, resulting in higher accuracies. The PN ranging signals described in CCSDS 415.1-B-1 and CCSDS 414.1-B-2 may be used for this purpose. Frame ranging involves timestamping and identification of synchronized information frames. It is particularly useful in high-rate communications links, where elevated data frame rates facilitate more accurate time resolution. A frame ranging standard is TBD (LNIS-TBD-3009).

3.2.5 TWO-WAY TRANSPONDER

Two-way transponder services support a similar process as described in section 3.2.4, however, with the LunaNet and user roles reversed. In the transponder scenario, the user generates the source signal, and an LNSP node transponds that signal and returns it to the user, as depicted in Figure 13. Users must then be capable of performing the two-way Doppler and range measurements on the signal the LNSP sends back to them.

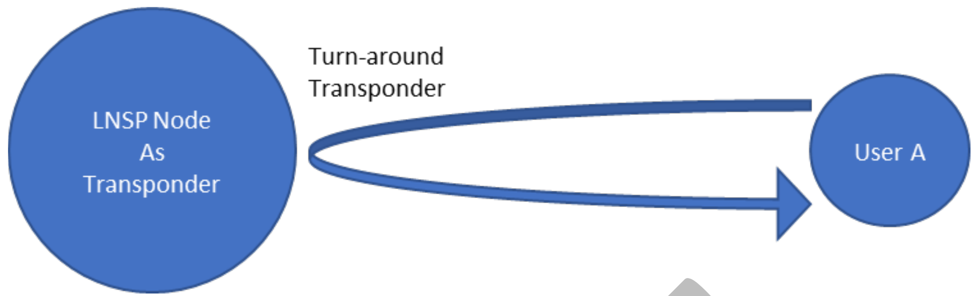

Figure 13: Two-Way LNSP Node Transponder

3.2.5.1 TWO-WAY COHERENT DOPPLER TRANSPONDER

In support of user two-way Doppler measurements, the LNSP node coherently relates its transmitted frequency to the frequency received from the user. The turn-around ratios applied by LunaNet nodes are the inverse of the ratios employed by user transponders to maintain the frequency allocations assigned.

3.2.5.2 NON-REGENERATIVE RANGE TRANSPONDER

In addition to what is performed for the two-way Doppler transponder service, a non-regenerative LNSP transponder filters and re-modulates the ranging signal onto the forward signal. The LNSP does not require knowledge of the ranging signal type employed by the user. The bandwidth allocated to the ranging signal and used by the LNSP for filtering shall be TBD (LNIS-TBD-3010).

3.2.5.3 REGENERATIVE RANGE TRANSPONDER

The regenerative ranging transponder service involves PN code acquisition by the LNSP, followed by the transmission of a synchronized PN ranging signal transmitted to the user. The PN ranging signals described in CCSDS 415.1-B-1 and CCSDS 414.1-B-2 may be used for this purpose.

3.2.6 SUPPLEMENTAL NAVIGATION PRODUCTS

Additional navigation products are defined to support the PNT services. Messages linked to such products are described in Appendix D. This section provides an overview of the supplemental navigation products.

3.2.6.1 LUNAR REFERENCE FRAME

The use of a common lunar-centered, selenocentric reference frame across LNSP PNT services enables seamless consumption of the services, regardless of specific LNSP or users. The lunar reference frame will be described in detail in Lunar Reference System Standard (LNIS-TBD-3011). Each LNSP shall either provide self PVT and ephemeris information in the common specified lunar reference frame or provide a means for the necessary coordinate transformations with respect to the specified lunar reference frame.

3.2.6.2 LUNAR REFERENCE TIME

The use of a common lunar reference time across LunaNet elements is required to enable synchronization of services and time in the lunar domain. This common lunar reference time will be described in detail in Lunar Time System Standard (LNIS-TBD-3012). Each LNSP shall provide PNT services either directly synchronized with the Standard Lunar Time (SLT) or provide a means for the necessary time corrections to achieve Standard Lunar Time.

3.2.6.3 LUNAR POTENTIAL MODEL

To ensure alignment for navigation services and products, a consistent set of coefficients that represent the lunar gravity model in degree and order will be defined in Lunar Reference System Standard (LNIS-TBD-AD0005) and the coefficients can be distributed by LNSP provider nodes.

3.2.6.4 LUNAR ORIENTATION PARAMETERS

Similar to Earth Orientation Parameters, the oscillations of the lunar principal axis undergo precession and nutation that can be described in parametric form, this will be defined in Lunar Reference System Standard (LNIS-TBD-AD0005) and distributed by LNSP provider nodes.

3.2.6.5 CONSTELLATION ORBITAL PARAMETERS

To plan and acquire services from LNSP constellations, users need almanacs that provide coarse orbital information for each of the provider nodes. This covers the complete set including all LNSPs. In addition, there is a provision for LunaNet nodes to distribute ephemeris information for Earth-centric GNSS constellations in support of receivers using weak signals from the Earth-centric GNSS.

3.2.6.6 MAP DISSEMINATION

To serve the navigation needs of users, LunaNet can distribute messages that contain information on lunar maps. This covers sectored maplets, version numbers, and complete high-resolution digital elevation maps.

3.2.6.7 CONJUNCTION DATA

To aid space situational awareness and avoid collisions between resident space objects, LNSPs will disseminate conjunction data in MSG-G14.

3.2.6.8 ASSET SPECIFIC PARAMETERS

Information specific to either a provider node or a user may be needed to improve navigation knowledge and insight. This includes maneuver information, state estimation covariance, estimator state transition matrix, and attitude/orientation.

3.2.7 LOCATION SERVICE

An LNSP can implement location services as part of their service portfolio. This service provides a computation of the user's PVT based on observations received by the LNSP nodes and disseminates the product via MSG-G7. The LNSP capable of carrying out location services receives observations from multiple sources via MSG-G13. Other messages may be needed as a supplement if measurements were obtained by other LSNP assets, such as MSG-G4 and MSG-G1. These observations are routed to the navigation system responsible for deriving the user's position and velocity, and potentially time. A request for location services includes necessary information for performing location or orbit determination for a specific user. Additional information on the location service will be defined in [AD4].

3.3 MESSAGING SERVICES

Messaging services will provide a standard way for messages to be transferred between a user node and provider node or between two provider nodes using any of the available interfaces.

These messaging services will be utilized by LunaNet protocols. LunaNet protocols are protocols for service acquisition, PNT, network management, alerts, and other LunaNet services, such as space weather and LunaSAR. The messaging services are not intended for user data flows outside of LunaNet protocols. Though these data flows between a user and provider or between provider nodes may sometimes be referred to as "control plane data," not all the protocols using the messaging resemble traditional control plane protocols. Note that the messages will be using the same physical links used for the user data. The number and type of LunaNet protocols is expected to evolve over time. The Messaging Service standard, LNIS-TBD-3003, will determine how LunaNet protocol messages are carried within any of the communications services and interfaces.

A generic use of the messaging service is shown below in Figure 14. Messages are being exchanged between a LNSP node and a user as part of the execution of a LunaNet protocol. The messages being exchanged are formatted within a standardized messaging format and carried over the standards to be defined.

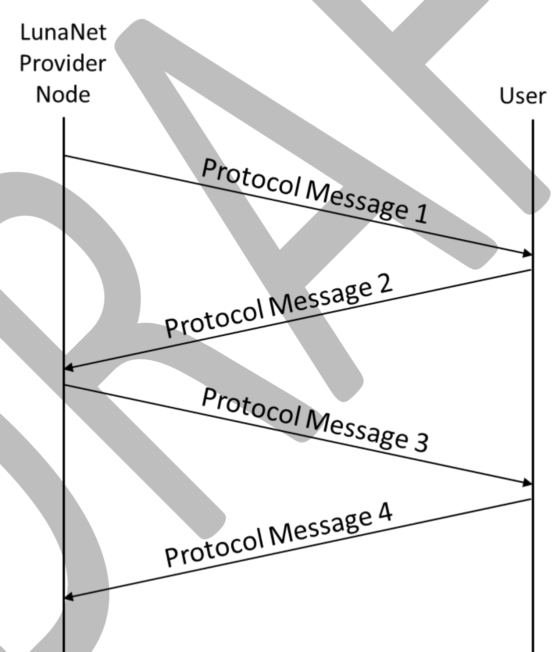

Figure 14: LNSP Node and user exchange messages using messaging services

The messaging services will provide methods for identifying message priorities. A publish and subscribe capability may be used for this service, except for specific messages needed for PNT observables via the PNT reference signals described in section 3.2.1. The AFS link, described later in this document, will carry messages differently than the other space links due to the lower data rate available.

The specific standards for the messaging services are still being determined. Until the messaging services are in place, the LunaNet protocol messages will be transported along with the user application as depicted in Figure 5. For ease in interpreting the remainder of this document, the message IDs and titles are provided in Table 4. Additionally, Appendix D provides information on the LunaNet protocol messages expected to be carried on the AFS link.

Table 4: Message ID and Titles

Message ID	Message Title
MSG-G1	LunaNet Network Access Information
MSG-G2	Health and Safety
MSG-G3	MAntennaProperties
MSG-G4	SOrbit Ephemeris+Clock correction
MSG-G5	MOrbit Almanac
MSG-G6	SOrbit Almanac
MSG-G7	SOrbitState /Location
MSG-G8	Time of transmission
MSG-G9	Time and Frequency Synchronization (frame)
MSG-G10	Maneuver
MSG-G11	SAttitude State/Ephemeris
MSG-G12	MAttitudeEphem
MSG-G13	Observations
MSG-G14	Conjunction
MSG-G15	Maplet
MSG-G16	Map Comprehensive
MSG-G17	Ancillary info
MSG-S18	Search and Rescue Alert
MSG-S19	Acknowledge- of SAR - LvL1
MSG-S20	Acknowledge- of SAR - LvL2
MSG-G21	User Message Request
MSG-G22	Acknowledge- of non-SAR MSG
MSG-G23	GNSS Augmentation
MSG-G24	Detection Alert
MSG-G25	Science
MSG-G26	UIS Request
MSG-G27	UIS Response
MSG-G28	User Schedule Notice
MSG-G29	FF Commands

3.4 DETECTION AND INFORMATION SERVICES

Detection and information services include LunaNet protocols within the network infrastructure to support alerts and critical information for user operations. Examples include space weather alerts triggered by instrumentation within provider systems and Lunar Search and Rescue (LunaSAR) beacon detection and location. These applications would generate and transmit messages using the formats and interfaces described in Appendix D. These services would have standard messages specific to their functions, such that all users receiving the messages will be able to understand them. The messages would be communicated using the messaging services described in 3.3.

Table 5: Detection and Information Services

Service	Description	Required Interop Standards
LunaSAR	Determines user location and gathers critical user status	LunaSAR Message Content / Format Distress Message Prioritization Possible signal design
Space Weather	Alerts and other relevant information concerning Space Weather	Space Weather Messages

3.4.1 LUNAR SEARCH AND RESCUE SERVICES

LunaSAR services enable users to report location and distress information via internationally recognized messaging standards modelled after current state-of-the-art messaging content used in terrestrial search and rescue (SAR) activities.

LunaSAR services require a combination of reception, prioritization, and re-broadcast/pass-through of distress messages on LNSP direct with Earth (DWE) and proximity links. LunaSAR message content is defined via inputs from the extravehicular activity (EVA) user community and SAR best practices.

LunaSAR messages leverage rotating field definitions to reduce message size, allowing for robust low-data-rate message transmissions from disadvantaged users to the LunaNet constellation at low power requirements and constrained link-budgets. LunaSAR services include location reporting of distress information, and low-data-rate bi-directional messaging between LunaSAR beacon users and message recipients such as Earth-based mission controllers, lunar surface assets, and lunar base camps.

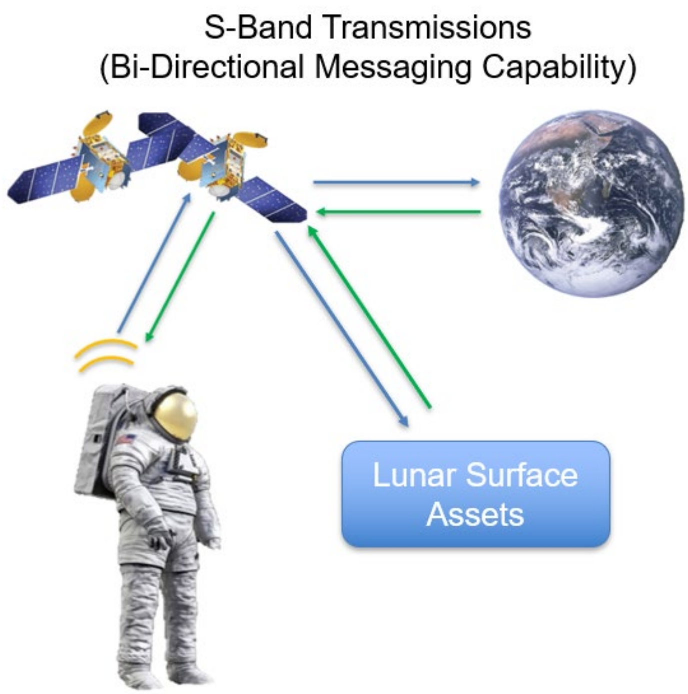

Figure 15: LunaSAR Data Path Concept of Operations

Four main steps describe the LunaSAR concept of operations and associated links:

1. **Distress signal broadcast (beacon to LNSP link):** The low power SAR beacon will transmit a distress signal that needs to be received by one or more LNSP nodes. The distress message might include the position of the beacon (if determined through the PNT services) or the beacon position might be computed by the LNSP (or another actor) via triangulation of the beacon as received by multiple LNSP nodes. A beacon might not know where the LNSP satellites are and might not have directive antenna capabilities, so the distress message might be broadcast and arrive at the LNSP with low power, this might require a dedicated, protected band. See Figure 18.
2. **Distress signal processing and start of rescue operation (LNSP node to Earth):** The distress message is sent to Earth for processing and activation of the rescue operation. A return message to the distress source is generated. Note: in the future, a SAR control center might be located on the Moon's surface.
3. **LunaSAR return message (LNSP node to beacon link):** The return message to the beacon is broadcast by the LNSP node. This message serves to inform the beacon that the distress message has been received and the rescue operation is ongoing. Considering the potential limitations of the user in terms of communications capabilities, the return message will be broadcast as part of the AFS signals but can also be provided via direct P2P links if available.
4. **Rescue operation completion (links LNSP to/from beacon):** During the rescue operation, and until completion, there might be multiple activities and links being utilized (dedicated P2P communications links if available).

LunaSAR's distress alert service is potentially received on PRS5 (LNIS4-TBR-3001) and responded to over the PFS5 (LNIS4-TBR-3001) links and are prioritized for rebroadcasting when received by the LNSP orbiting asset(s). Prioritization aligns with the principles of terrestrial distress tracking services commercially available to those engaged in dangerous activities.

LunaSAR messages are notionally formatted in Concise Binary Object Representation (CBOR) formatting to allow for increased processing and transfer speeds between LunaSAR users and users. Note that rotating field messages described in this section are for example only and can be tailored to the specific lunar distress application/end-user hardware development. For example, message content would be derived from telemetry streams that could be monitored for faults and trigger automated distress message generation. (i.e., space suit pressure issue, radiation exposure, etc.) This process mimics current International Maritime Organization and International Civil Aviation Organization provisions for automated distress tracking and notification services and will be replicated as applicable within the lunar domain as the infrastructure evolves.

LunaSAR service broadcasts begin upon manual or automated triggering of distress transmissions and do not broadcast unless required. This aligns with the terrestrial standard for Cospas-Sarsat beacons and serves to preserve the nominal bandwidth within the relay system. Repetition rates following beacon/distress mode activation as well as signals and signal bandwidths used for the first step (distress beacon signal broadcast) are detailed in a separate document [AD7]. The PFS5 broadcast signals will include messages implementing the LunaSAR response to inform the distress beacon source that their request has been received and rescue actions are ongoing, this does not exclude sending the LunaSAR response also via other channels (e.g., P2P communication channels if available).

3.4.2 SPACE WEATHER ALERTING SERVICES

Space weather alerts and related messages will be communicated using the messaging services, per Appendix D. The specific standard alert and message content are still TBD (LNIS-TBD-3013-2). Initiation of space weather alerts could be native to the LNSP node in lunar orbit if suitable instrumentation is present, or it could be received from another asset (space or Earth) and relayed accordingly to users in the lunar proximity.

3.5 SCIENCE SERVICES

LNSP assets may be able to support science objectives by using available radio/optical links and telemetry. Some science services may only require that LNSP space equipment operate in a special mode within the capabilities of the communications and navigation subsystem. These services may require standardized message formats to collect and share measurements from the variety of possible LNSP systems.

3.6 SERVICE ACCESS

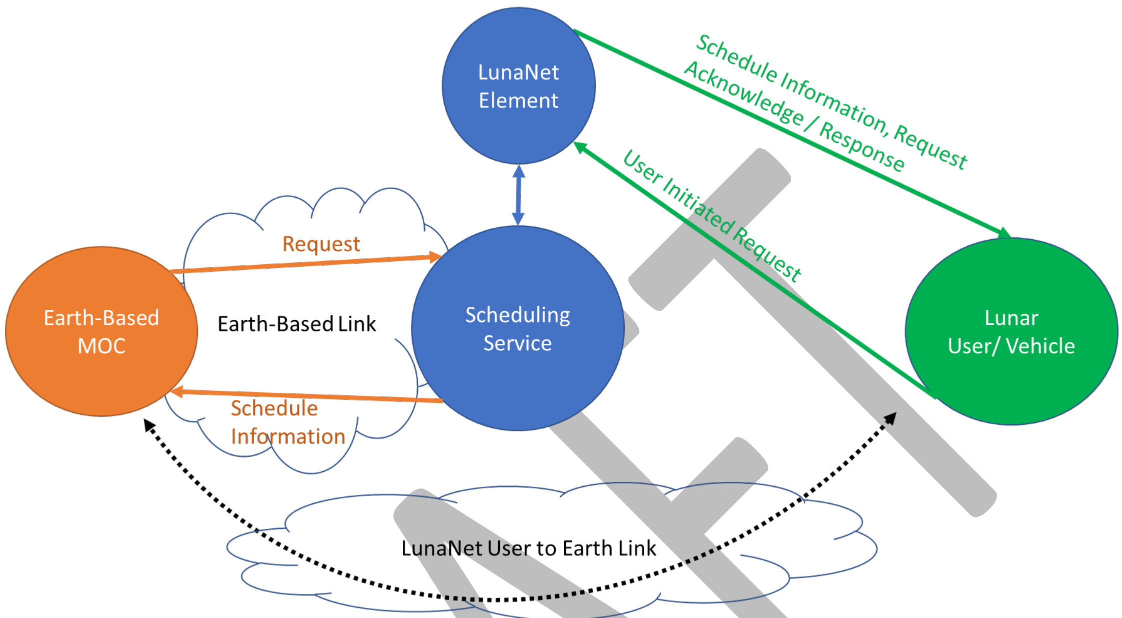

Figure 16: LunaNet Scheduling Interfaces Overview

Users will be able to access services through a variety of methods. See Figure 16. Services may be scheduled through an LNSP's scheduling service that allows a mission operations center to pre-schedule services with a LNSP. Users that employ the services of more than one LNSP must schedule service separately with each LNSP and maintain their mission-specific combined schedule. Standardized methods for allowing one LNSP to schedule services with another LNSP on behalf of a user are desired.
Users accessing Multiple Access links may still need some level of macro mission level scheduling. For example, the user needs to inform the LNSP so they can ensure assets are maintained and available. User Initiated Services (UIS) will allow users to request and receive services over links between the user and an LNSP node.

Space Frequency Coordination Group (SFCG) Provisional Recommendation: SFCG 42-1 defines the S-band frequency channel plan for lunar relay satellites such as LNSP nodes according to different service access methods[1]. Future versions of the LNIS will clarify and specify the applicability of Recommendation SFCG 42-1 to the LNIS Service Access methods[2]. The LunaNet Service Access methods are defined here in this context. The method of accessing the services can vary depending on the service access band.

[1] Provisional Recommendation SFCG 42-1 defines frequency bands for S-band In-situ Lunar Relays only. It is anticipated that future revisions of the recommendation will define the frequency bands for K-band Lunar Relays, and it is planned that these recommendations will be adopted by LNIS when published.

[2] There are some differences in use of terminology between the existing LNIS Service Access methods and the provisional SFCG 42-1. SFCG 42-1 is currently a provisional recommendation and the SFCG is collecting feedback from member space agencies, and LNIS planners will provide feedback to the SFCG on these items.

3.6.1 EARTH-BASED SCHEDULING SERVICE

Earth-based scheduled services are those where the request originates from the user's Earth-based mission control center to the LNSP. The LNSP will make the necessary arrangements to confirm availability of the requested service given the available resources and then confirm the services scheduled with the user.

Each LNSP may have their own unique interface for Earth-based schedule requests. No standards for this interface have been identified yet. The CCSDS 902.1-B-1 Simple Schedule Format Specification is a starting point for the identification of the full standards required.

User services scheduled using the Earth-based scheduling service may access the service in the Single Access or Multiple Access bands allocated for lunar user proximity links defined by SFCG 42-1.

3.6.2 USER INITIATED SERVICES

User Initiated Services (UIS) give lunar user assets the capability to autonomously access the lunar communications infrastructure to report periodic telemetries, inform on anomalies, and request services or network resources from the service provider. Additionally, it also allows mission owners/service providers to track user assets and task them at any time.

Following the receipt of a UIS request, the LNSP will manage the request and allocate resources according to their availability, as well as established orchestration and service level agreement policies.

The UIS process may be executed through service acquisition protocols utilizing a combination of previously scheduled services or available interfaces. These options are detailed below and are still being determined (LNIS-TBD-3014):

- The Multiple Access Return link provides a highly available link for unscheduled access for initiating service requests.
- The AFS provides a highly available link for unscheduled network responses to requests.
- For UIS conducted using service acquisition protocols incorporating the Messaging Service, this is anticipated to be able to be conducted over any available communications path.
- An adaptation of the CCSDS Proximity-1 hailing process is under consideration as a physical mechanism for UIS.

The use of a UIS protocol over messaging channels or through hailing methods would be used for any services in any frequency band. For example, K-band UIS might be possible using the S-band hailing method (i.e., dual band terminals) or a dedicated K-band hailing mechanism. Broadcast channels such as LANS could support UIS as well.

3.6.3 SINGLE ACCESS LINKS

A variety of Single Access signal types are defined with specified signal parameters to provide a range of options supporting interoperability in terms of symbol rate, bandwidth efficiency, robustness, implementation complexity, and support for ranging. A summary of these signals is provided in Table 7 in section 4.2 with further signal specifications shown in Appendix B.

Single Access services in LunaNet are defined as those where an LNSP and a single user utilize a specific frequency channel to communicate on an exclusive basis, either for the duration of the session only or exclusively for the mission duration. This would be subject to agreement between the LNSP and user. In this context, Frequency Division Multiple Access and Time Division Multiple Access schemes are collectively referred to as Single Access services. Single Access Links can be accessed through Earth-scheduled or UIS means.

3.6.4 SPREAD SPECTRUM LINKS

There are two types of spread spectrum signal formats defined, one to provide low-rate CDMA services and another to provide medium rate P2P services with spread spectrum PN ranging.

The broadcast forward signal PFS5 is referred to as the AFS. The PFS5 signal is unique in that it has a fixed frequency outside of the S-band proximity forward and return service bands and has a special role in navigation services.

The CDMA return signal PRS5 is the signal interface of the Multiple Access Return (MAR) service. The PRS5 signal operates with a fixed center frequency and high spreading ratio, allowing many users to share the channel.

Other multiple access schemes that may be operated by LNSPs to deliver services, such as Frequency Division Multiple Access or Time Division Multiple Access are considered to be Single Access services in this context.

The spread spectrum signals PRS2 and PFS2 utilize a spread spectrum format similar to CDMA but are intended for P2P usage. They utilize a lower spreading ratio than PRS5 and PFS5, enabling higher data rates than the multiple access services.

Each of these signals will be further introduced in the following sections. Table 8 provides a summary of these signals, and further specifications are given in Appendix B.

3.6.4.1 AUGMENTED FORWARD SIGNAL (AFS) SERVICE

A multiple access forward link is being implemented using the AFS design. The signal, represented as PFS5 in the LNSP-User Proximity Interfaces and further described in Appendix C, will provide navigation and ancillary communications services simultaneously to multiple users in the lunar region without the need for a user to establish dedicated proximity links with a particular LNSP element. A single frequency will be used for the AFS signal and systems will be optimized to maximize coverage and availability for users. This optimization will likely lead to a lower available data rate, so the AFS data will be restricted to certain LunaNet protocol messages, as defined in Appendix D.

In addition, the AFS serves as an entry point to the LNSP network. Users entering the service volume acquire the AFS signal and obtain a coarse state of services available. This service enables LNSPs to provide users with important information and data, such as contact information, schedule, service availability, position of different LNSP elements, and acknowledgement of user requests or receipt of messages. Given the ubiquitous nature of the service, it serves as a dissemination channel for relevant notifications and alerts via provision of standard messages (3.3) and LunaSAR response messages (3.4.1).

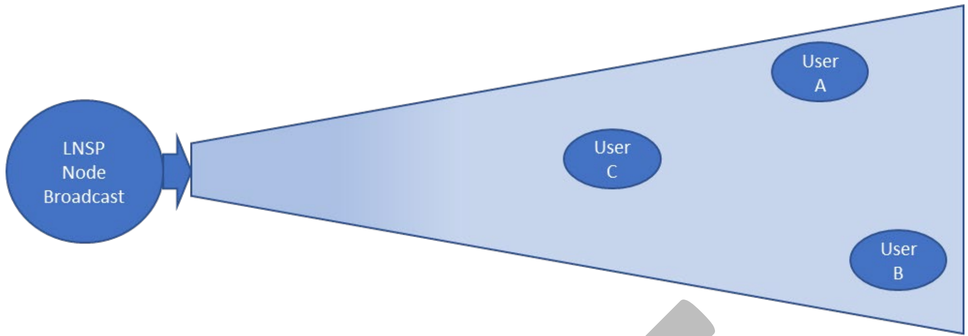

Figure 17: Augmented Forward Signal Service Provided by a Single LNSP Source

Refer to Appendix C for AFS signal structure definition and message requirements.

3.6.4.2 MULTIPLE ACCESS RETURN (MAR) SERVICE

The multiple access return link provides users with a highly available interface to initiate service requests, send situational awareness messages, or send SAR alerts through LNSP. Multiple access return links may also be used for low-rate user telemetry and science data. Refer to Appendix D for supporting message definitions. The PRS5 CDMA signal design will support simultaneous links from multiple users and the PNT functions described in section 3.2.

3.6.4.3 SPREAD SPECTRUM P2P SERVICES

Dedicated, medium data rate spread spectrum access links are specified in both forward and return directions (PFS2 and PRS2). These are intended for P2P links for real-time and store-and-forward data at a medium data rate and ranging.

The intent is that the spreading ratios of these dedicated links can be customized to meet the user needs. As spread spectrum signals, there is a possibility that multiple users could share a single PFS2/PRS2 frequency channel with careful coordination. For example, a distributed science mission utilizing several instruments in near proximity may choose to utilize a single PRS2 channel that all science instruments share, enabling a simultaneous return on a single scheduled session. The symmetric nature of the signals permits two-way services.

3.6.5 LINK ESTABLISHMENT

Link establishment is required for both Earth-scheduled and UIS, although in the former case the process is simplified if the user and LNSP node are pre-configured with the necessary transceiver parameters. The standards for link establishment are TBD (LNIS-TBD-3015) and will likely vary depending on whether the user is accessing a Single Access or Multiple Access LunaNet service.

The current UHF Proximity-1 protocol includes a hailing and link establishment mechanism which is under consideration for Single Access Services with regards to the S-band and Ka-band evolution of Proximity-1. Note that Proximity-1 is under consideration as a standard for both UIS and Earth-scheduled Single Access services. This is to make use of the defined link establishment and hailing mechanism integral in the protocol, which includes the flexibility for demanded or negotiated link establishment and support for half-duplex and full duplex hailing. The use of an adapted CCSDS Proximity-1 Physical Layer Protocol[3]

[3] Assuming a future evolution of CCSDS Proximity-1 Physical Layer Protocol 211.1-B to include extension of the Proximity-1 UHF Physical Layer protocol to additional frequency bands.

for hailing on Single Access services will require a dedicated hailing channel to be reserved within the SFCG 42-1 bands.

3.7 SERVICE COMBINED CAPABILITIES AND INTER-RELATIONSHIPS

It is anticipated that users will be able to make productive service combinations to enhance and augment their communications and navigation capabilities.

Examples of this approach include but are not limited to:

- Use of the LANS service by a lunar user to determine user position, relay position, and time synchronization in order to accurately point a directive antenna towards an LNSP relay and utilize the Communications Service.
- Use of the LANS service by a lunar user to maintain tracking for a directive antenna during a Communications Service session.
- Delivery of Earth-scheduled session configuration information to a lunar user via the Messaging Service for configuration of a future real-time or store-and-forward communications session.
- Use of the One-Way Measurement or Two-Way Measurement service for Doppler and ranging measurements to establish a lunar user's PVT or orbit determination in order to pre-configure the LNSP relay for a future Communications Services session.
- Use of the Communications Service to enhance or augment the AFS/LANS service, for instance to provide additional or higher accuracy navigation products, or distribution of authentication keys to the user.

The use of LNSP services in an inter-related manner is considered an opportunity to provide enhanced capabilities, however each service is considered independent in its own right from a service delivery perspective. LNSPs are encouraged to provide at least a basic means in their service delivery model for their services to be accessible to users without dependency on another service in order to maximize interoperability and provision for fallback and recovery scenarios.

4 LUNANET SERVICE PROVIDER TO USER INTERFACES

The functional interfaces and corresponding frequency bands for lunar radio frequency links are shown in the following sections. Allowable signal bandwidths and power levels will be determined through the spectrum management process. Standards for optical link interfaces are TBD (LNIS-TBD-4001). Communications link frequency ranges are specified in Figure 18.

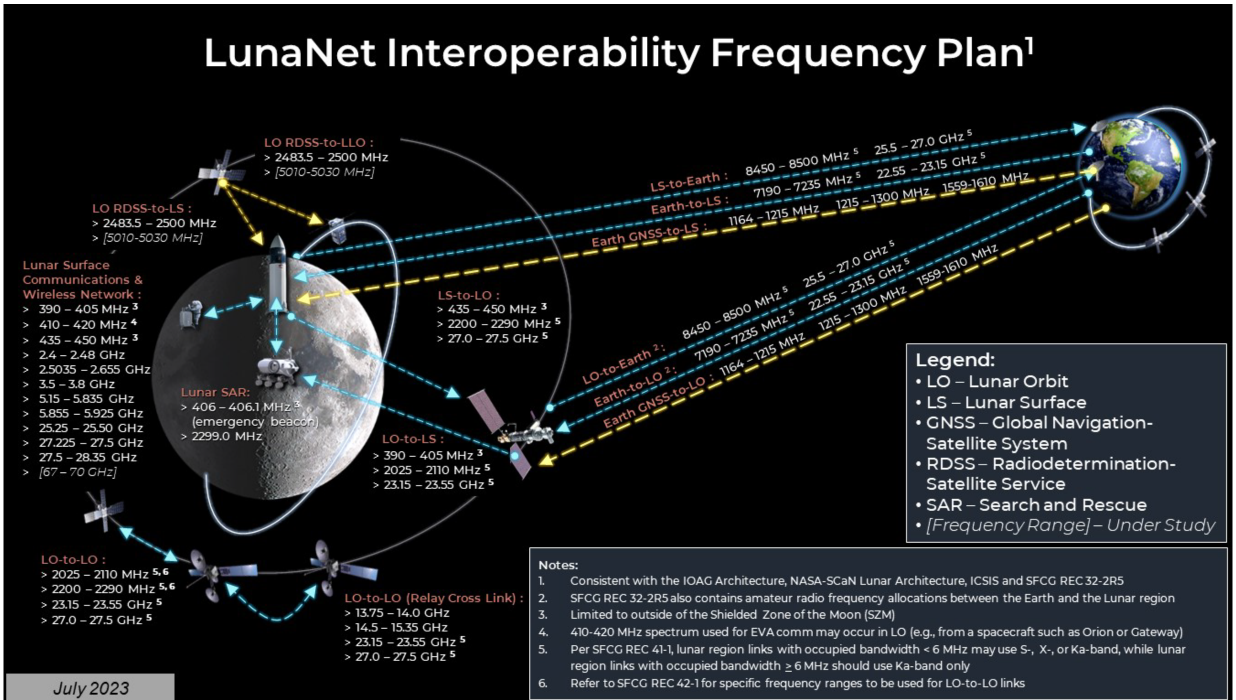

Figure 18: LunaNet Interoperability Frequency Plan

The LunaNet spectrum architecture complies with the SFCG Recommendation 32-2R5 with the following notes:

- SFCG 32-2R5 allows use of both the near-Earth S-band (2025-2110 MHz forward, 2200-2290 MHz return) and X-band (7190-7235 MHz forward, 8450-8500 MHz return) for DWE links between Earth and lunar regime.
    - However, due to increasing congestion in the S-band, LunaNet restricts use of S-band to lunar proximity links while X-band is used for DWE links. This enables reuse of the S-band in the cislunar region.
- SFCG 32-2R5 identifies several frequency band allocations that have not been approved by the International Telecommunication Union Radiocommunication Sector (ITU-R) in its regulations, including:
    - Lunar Surface Wireless Network: Frequency bands for proposed cellular service based on 3rd Generation Partnership Project (3GPP – The Mobile Broadband Standard) standards are under investigation.
    - Lunar Orbit Radio Navigation Satellite Service (RNSS) to Lunar Surface: Use of the 5010-5030 MHz band for PNT service requires ITU-R action.
- SFCG 32-2R5 includes use of optical communications links. LNIS anticipates including optical links in the future but does not address them in this version.

4.1 LNSP-USER LUNAR SURFACE INTERFACES

This section provides a list of the lunar surface signal interfaces.

Table 6: LNSP–User Lunar Surface-Surface Link Layer Service Interfaces

Interface name	Interface Type	Description	Targeted Frequency Range[1]	Applicable Documents
LS1	Short-range wireless network	Wi-Fi 6, Wi-Fi Certified AC	5.150-5.835 GHz Lunar near-side only LNIS4-TBR-4001	CCSDS 883.0-B-1 SFCG 32-2R5
LS2	Short-range wireless network	Wi-Fi 6, Wi-Fi Certified N	2.4-2.48 GHz	CCSDS 883.0-B-1 SFCG 32-2R5
LS3	Short-to-medium range wireless network with mobility and roaming	3GPP rel. 16 (and higher) LTE and 5G LNIS-TBD-4002	LNIS-TBD-4003	CCSDS 883.0-B-1

[1] The exact frequency channel(s) have not been determined and are subject to coordination.

[2] SFCG 32-2R5 identifies the need to provide sufficient out of band filtering to protect the 2483.5-2500 MHz lunar orbit to lunar surface PNT band.

A. Potential 3GPP bands should not overlap with SRS, SOS, ISS, RAS, RNSS, and RDSS bands, as defined by the SFCG.
B. In wireless communications using 3GPP, uplink / reverse link is defined as a lunar surface user (astronaut/rover) to a lunar surface base station (lander/tower). The downlink / forward link is defined as a lunar surface base station (lander/tower) to a lunar surface user (astronaut/rover).
C. 5.25-5.57GHz is allocated to SRS (active) on a primary basis; use of these frequencies for communications in the lunar region is on a non-interference and unprotected basis to SRS (active).

4.2 LNSP-USER PROXIMITY INTERFACES

This section provides an overview of the signal formats across proximity links between LNSPs and users. A summary of the single access proximity signal interfaces is shown in Table 7. The full specification of each signal is found in Appendix B. The ID column is used to identify the unique signal interfaces described in Appendix B. The ID values in the tables are hyperlinked to provide quick navigation to the relevant section of Appendix B.

Table 7: LNSP-User Proximity Interfaces Single Access

	Frequency	**ID**	**Modulation**	**Symbol Rate**	**Ranging**	**Summary**
S-band	Forward 2025-2110 MHz	PFS1a	Filtered BPSK	Min: 2 ksps Max: 2.048 Msps	No	BPSK modulation common on existing S-band links.
		PFS1b	PCM/PM	Min: 48 ksps Max: 1.024 Msps	PN Ranging	Data on carrier, option for ranging on residual carrier. Medium Data Rates.
		PFS1c	PCM/PSK/PM	Min: 0.5 ksps Max: 48 ksps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Low Data Rates.
		PFS1d	Filtered OQPSK or GMSK	Min: 1 Msps Max: 5 Msps	No	Higher order modulation for higher data rates, without ranging.
		PFS1e	GMSK+PN	Min: 1 Msps Max: 5 Msps	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.
	Return 2200-2290 MHz	PRS1a	Filtered BPSK	Min: 2 ksps Max: 2.048 Msps	No	BPSK modulation common on existing S-band links.
		PRS1b	PCM/PM	Min: 48 ksps Max: 1.024 Msps	PN Ranging	Data on carrier, option for ranging on residual carrier. Medium Data Rates.
		PRS1c	PCM/PSK/PM	Min: 0.5 ksps Max: 48 ksps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Low Data Rates.
		PRS1d	Filtered OQPSK or GMSK	Min: 1 Msps Max: 5 Msps	No	Higher order modulation for higher data rates, without ranging.
		PRS1e	GMSK+PN	Min: 1 Msps Max: 5 Msps	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.
K-band	Forward 23.15-23.55 GHz	PFK1	Filtered BPSK	Min: 1 Msps Max: 2.048 Msps	No	BPSK given as option for simplest, low-rate Ka-band system.
		PFK2	DVB-S2, SCCC, or LDPC-VCM	Min: 1 Msps Max: {TBD}	No	VCM schemes enable spectrally efficient higher data rates.
		PFK3	Filtered OQPSK or GMSK	Min: 1 Msps Max: {TBD}	No	OQPSK (or GMSK) modulation common on existing K-band links.
		PFK4	GMSK+PN	Min: 1.5 Msps Max: {TBD}	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.
	Return 27.0-27.5 GHz	PRK1	Filtered BPSK	Min: 1 Msps Max: 2.048 Msps	No	BPSK given as option for simplest, low-rate Ka-band system.
		PRK2	DVB-S2, SCCC, or LDPC-VCM	Min: 1 Msps Max: {TBD}	No	VCM schemes enable spectrally efficient higher data rates.
		PRK3	Filtered OQPSK or GMSK	Min: 1 Msps Max: {TBD}	No	OQPSK (or GMSK) modulation common on existing K-band links.
		PRK4	GMSK+PN	Min: 1.5 Msps Max: {TBD}	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.

A summary of the spread spectrum proximity signal interfaces is shown in Table 8. The full specification of each signal is found in Appendix B. The ID column is used to identify the unique signal interfaces described in Appendix B. The ID values in the tables are hyperlinked to provide quick navigation to the relevant section of Appendix B.

Table 8: LNSP-User Proximity Interfaces Spread Spectrum

	Frequency	ID	Modulation	Symbol Rate	Ranging	Summary
S-band	Forward 2025-2110 GHz	PFS2	SS-BPSK {TBD}	{TBD}	Spread spectrum PN	Spread spectrum PN w/ ranging, low spreading ratio for medium data rates.
S-band	Return 2200-2290 MHz	PRS2	SS-BPSK {TBD}	{TBD}	Spread spectrum PN	Spread spectrum PN w/ ranging, low spreading ratio for medium data rates.
S-band	Return 2200-2290 MHz Fc: {TBD}	PRS5	SS-BPSK {TBD}	{TBD}	Spread spectrum PN	Multiple Access Return (MAR). Spread spectrum PN w/ ranging, high spreading ratio for low data rates, many users.
AFS	Fc: 2492.028 MHz BW: 16.5 MHz	PFS5	See Appendix C	See Appendix C	See Appendix C	See Lunar Augmented Navigation System (LANS)

4.3 LNSP-USER DWE INTERFACES

A summary of the DWE signal interfaces is shown in Table 9. DWE applies both to direct links between Earth and lunar surface and links between Earth and LunaNet relay nodes.

In this document the special case of the link between a lunar relay orbiter and Earth station is identified as the "trunk link." A trunk link exists in both the forward and return directions. The full specification of each signal is found in Appendix B. The ID field is used to identify the unique signal interfaces described in Appendix B. The ID values in the tables are hyperlinked to provide quick navigation to the relevant section of Appendix B.

Table 9: LNSP-User DWE signal interfaces

	Frequency	ID	Modulation	Symbol Rate	Ranging	Summary
X-band	Uplink 7190-7235 MHz	XU1	PCM/PM	Min: 64 ksps Max: 1.024 Msps	PN Ranging	Data on carrier, option for ranging on exposed residual carrier. Medium Data Rates.
		XU2	GMSK+PN	Min: 150 ksps Max: 1 Msps	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.
		XU3	PCM/PSK/PM	Min: 0.5 ksps Max: 64 ksps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Low Data Rates.
		XU4	Filtered OQPSK or GMSK	Min: 128 ksps Max: 10 Msps	No	Higher order modulation for higher data rates, without ranging.
	Downlink 8450-8500 MHz	XD1	PCM/PM	Min: 64 ksps Max: 1.024 Msps	PN Ranging	Data on carrier, option for ranging on exposed residual carrier. Medium Data Rates.
		XD2	GMSK+PN	Min: 150 ksps Max: 1 Msps	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.
		XD3	PCM/PSK/PM	Min: 0.5 ksps Max: 64 ksps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Low Data Rates.
		XD4	Filtered OQPSK or GMSK	Min: 128 ksps Max: 10 Msps	No	Higher order modulation for higher data rates, without ranging.
K-band	Uplink 22.55-23.15 GHz	KU1	Filtered OQPSK or GMSK	Min: 2 Msps Max: 50 Msps {TBR}	Frame Ranging	OQPSK (or GMSK) modulation common on existing K-band links.
		KU2	GMSK+PN	Min: 2 Msps Max: 50 Msps {TBR}	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.
	Downlink 25.5-27.0 GHz	KD1	Filtered OQPSK or GMSK	Min: 2 Msps Max: 200 Msps {TBR}	Frame Ranging	OQPSK (or GMSK) modulation common on existing K-band links.
		KD2	GMSK+PN	Min: 2 Msps Max: 200 Msps {TBR}	PN Ranging	GMSK+PN per CCSDS standards. High Data Rates w/ Ranging.

4.4 LNSP-USER CONTINGENCY INTERFACES

A summary of the contingency mode signal interfaces is shown in Table 10. Contingency mode signals are those used during off nominal or emergency states when power is limited, or antenna pointing is compromised. The full specification of each signal is found in Appendix B. The ID column is used to identify the unique signal interfaces described in Appendix B. The ID values in the tables are hyperlinked to provide quick navigation to the relevant section of Appendix B.

Table 10: LNSP-User Contingency Mode Signal Interfaces

	Frequency	ID	Modulation	Symbol Rate	Ranging	Summary
Proximity S-band	Forward 2025-2110 MHz	PFC1a	PCM/PSK/PM	15.625 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Lowest rate used for very weak signal links.
		PFC1b	PCM/PSK/PM	250 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Higher rate to provide flexibility in cislunar space.
	Return 2200-2290 MHz	PRC1a	PCM/PSK/PM	15.625 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Lowest rate used for very weak signal links.
		PRC1b	PCM/PSK/PM	250 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Higher rate to provide flexibility in cislunar space.
DWE X-band	Uplink 7190-7235 MHz	CU1	PCM/PSK/PM	15.625 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Lowest rate typically used for deep space.
		CU2	PCM/PSK/PM	250 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Higher rate to provide flexibility in cislunar space.
	Downlink 8450-8500 MHz	CD1	PCM/PSK/PM	20 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Lowest rate typically used for deep space.
		CD2	PCM/PSK/PM	250 sps	PN Ranging	Data on subcarrier, option for ranging on residual carrier. Higher rate to provide flexibility in cislunar space.

4.5 LNSP-USER TERRESTRIAL INTERFACES

A summary of the signal interfaces between the LNSP and the user mission operation centers on Earth are shown in Table 11 below.

Table 11: LNSP–User Terrestrial Link Layer Service Interfaces

Service Interface ID	Interface Type	Applicable Documents
SLE RAF	Space Link Extension Return All Frames	CCSDS 911.1-B-4
SLE RCF	Space Link Extension Return Channel Frames	CCSDS 911.2-B-3
SLE FCLTU	Space Link Extension Forward CLTU	CCSDS 912.1-B-4
CSTS FFS	Cross Support Transfer Service Forward Frame Service	CCSDS 922.3-R-1

5 LUNANET SERVICE PROVIDER TO LUNANET SERVICE PROVIDER SERVICES

5.1 LNSP A-LNSP B COMMUNICATIONS SERVICES

Using standard interfaces, an LNSP will be able to provide the communications services described in section 3.1. This will enable LunaNet-compatible communications service infrastructure to be provided by multiple providers. Beyond the user data, there will be communications between LNSPs for scheduling, routing, asset availability, and other functions.

5.2 LNSP A-LNSP B PNT SERVICES

PNT services, as described in section 3.2 Position, Navigation, and Timing Services, may also be provided between assets belonging to two different LNSPs. This will be addressed in next version.

6 LUNANET SERVICE PROVIDER TO LUNANET SERVICE PROVIDER INTERFACES

6.1 LNSP A-LNSP B LUNAR SURFACE INTERFACES

These interfaces will follow the same standards as identified in section 4.1 LNSP-User Lunar Surface Interfaces.

6.2 LNSP A-LNSP B CROSSLINK INTERFACES

To allow end-to-end delivery of data of user data, cross-link interfaces shall be based on DTN BP for the network layer. Crosslinks will allow two LNSPs to pass user data between their assets, message between the assets, and provide PNT services.

LunaNet providers will be required to directly exchange information within the internal architecture, independently from DWE interfaces, to enable awareness of the overall service health, availability and status, current and future schedule, and time synchronization. Direct exchange of information within the LunaNet architecture will also allow for the use of observables for self-navigation purposes. This section will cover the required interfaces between providers to ensure resilient services independent from Earth links. These crosslinks are to be carefully designed such that they are compatible with user links (TBD).

Table 12: LNSP–LNSP Crosslink Layer Interfaces[4]

Interface Name	Interface Type	Targeted Frequency Range[3]	Modulation[4]	Coding[4]	Applicable Documents[2]
CFK1	Crosslink Forward[1]	23.15 – 23.55 GHz (LNIS-TBD-6001)	Filtered OQPSK and GMSK[2]	LDPC rate 1/2 (4096 octets plus 64-bit ASM) LDPC code rate 4/5 (2560 octets plus 64-bit ASM) LDPC rate 7/8 (1020 octets plus 32-bit ASM)	LNIS-TBD-6003
CRK1	Crosslink Return[1]	27.00 – 27.50 GHz (LNIS-TBD-6002)	Filtered OQPSK and GMSK[2]	LDPC rate 1/2 (4096 octets plus 64-bit ASM) LDPC code rate 4/5 (2560 octets plus 64-bit ASM) LDPC rate 7/8 (1020 octets plus 32-bit ASM)	LNIS-TBD-6004

[1] The “forward” or “return” designation is determined by the source and destination of a particular signal. If a signal originates at a lunar region user (orbiter, rover, lander, etc.) and is sent to LNSP-A, any subsequent links to LNSP-B, LNSP-C, etc. before being routed to a mission or science operations center would be at a “return” frequency (27.0 – 27.5 GHz). If data was sent by a science or mission operations center via an LNSP Earth station, then passed around nodes within an LNSP network before being delivered to a lunar region user, the links between LNSP nodes in this case would be at a “forward” frequency (23.15 – 23.55 GHz). Each LNSP will have the capability to transmit as well as receive crosslink signals from fellow LNSPs that are part of the service provider network.

[2] See CCSDS Preliminary Recommendation 2.2.10 on “High-Rate Space-to-Space Links, Space Research and Inter-Satellite.”

[3] Exact center frequency to be determined based on user requirements and concept of operations and are subject to coordination.

[4] Preliminary recommendations are TBD.

6.3 LNSP A-LNSP B DWE INTERFACES

These interfaces will follow the same standards as identified in 4.3 LNSP-User DWE Interfaces.

6.4 LNSP A-LNSP B TERRESTRIAL INTERFACES

These interfaces will follow the same standards as identified in section 4.5 LNSP-User Terrestrial Interfaces.

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APPENDIX A ACRONYMS

Table A-1 Acronyms

Acronym	Description
3GPP	3rd Generation Partnership Project
AFS	Augmented Forward Signal
AOS	Advanced Orbiting Systems
ASM	Attached Sync Marker
BER	Bit Error Rate
BP	Bundle Protocol
BPSK	Binary Phase Shift Key
CBOR	Concise Binary Object Representation
CLPS	Commercial Lunar Payload Services
CCSDS	Consultative Committee for Space Data Systems
CDMA	Code Division Multiple Access
CLTU	Command Link Transmission Unit
DEM	Digital Elevation Maps
DTE	Direct to Earth
DTN	Delay/Disruption Tolerant Networking
DWE	Direct with Earth
DVB-S2	Digital Video Broadcasting-Second Generation
ECSS	Europeans Cooperation for Space Standardization
ESC	Exploration and Space Communication
EVA	Extravehicular Activity
GMSK	Gaussian Minimum Shift Keying
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
ICMP	Information and Configuration Management Plan
IETF	Internet Engineering Task Force
IMO	International Maritime Organization
IOAG	Interagency Operations Advisory Group
IPIOC	Internet Protocol
IOC	Initial Operational Concept
KSPS	Kilo Symbols Per Second
LANS	Lunar Augmented Navigation System
LDPC	Low Density Parity Check
LNSP	LunaNet Service Providers
LTP	Licklider Transmission Protocol
MAR	Multiple-Access-Return
MHZ	Megahertz
MOC	Mission Operations Center
NPD	NASA Policy Directives

Acronym	Description
NPR	NASA Procedural Requirements
NRZ-L	Nonreturn-To-Zero Level
NTP	Netrix Trunk Protocol
OQPSK	Offset Quadrature Phase Shift Keying
P2P	Point to Point
PN	Pseudo-Noise
PNT	Position, Navigation, and Timing
PVT	Position, Velocity, and Timing
RD	Reference Document
RF	Radio Frequency
RFC	Radio Frequency Compatibility
RHCP	Right-Hand Circularly Polarized
SAR	Search and Rescue
SCaN	Space Communications and Navigation
SCCC	Spacecraft Command and Control Center
SFCG	Space Frequency Coordination Group
SS-BPSK	Spread Spectrum Binary Phase-Shift Keying
TBD	To Be Determined
TBR	To Be Refined
TCP/IP	Transmission Control Protocol/Internet Protocol
UDP	User Datagram Protocol
VCM	Variable Coding and Modulation
Wi-Fi	Wireless Fidelity

APPENDIX B SIGNAL INTERFACE DESCRIPTIONS

B.I LNSP-USER PROXIMITY INTERFACES

This section defines the specifications for the signal formats across proximity links between LNSPs and users. The following general notes apply to the LNSP-User proximity interfaces:

A. An adaptation of Proximity-1 protocols for the use of lunar missions in S-Band and K-band is currently under consideration and will be evaluated based on spectrum and other technical considerations. Reference CCSDS 211.0-B-6, CCSDS 211.1-B-4, and CCSDS 211.2-B-3. Further details will be disseminated in future LunaNet specification releases.

B. In order to ease acquisition tracking in the presence of large Doppler dynamics, Doppler compensation could be used. As a specific example, for users with very low signal strength that require very narrow bandwidths, Doppler compensation might be required.

C. When using shaped pulses (e.g., filtered OQPSK, GMSK+PN) at the lower limits of the data rate range, bit error rate (BER) degradation and/or synchronization issues can occur. At low data rates, the normalized loop bandwidth (loop bandwidth normalized to data rate) increases, which can result in BER degradation of the signal. Increasing the normalized loop bandwidth can allow for cycle slips in the tracking loop, which could result in link stability issues and can also degrade BER performance. The tracking loop bandwidth must be large enough to accommodate the link doppler rates, which is dependent on the specific geometry of each relay/user link. Developers and mission planners should ensure through hardware testing that the receiver can properly operate at the low data rates for the worst-case doppler scenarios that a specific user to relay (and relay to user) link will see.

D. Low-Density Parity Check (LDPC) codes are shown here in parenthetical (n, k) format, where n is the codeword length in bits and k is the information block length in bits. The code rate is also shown, although this can also be derived by $r = k/n$. CCSDS 131.0-b Section 7.3 describes the LDPC 7/8 (8160, 7136) code. CCSDS 231.0-b Section 4 describes the LDPC ½ (128, 64) and LDPC 1/2 (512, 256) codes. CCSDS 131.0-b Section 7.4 describes the remaining LDPC ½, LDPC 2/3, and LDPC 4/5 of various (n, k) values used in this specification. CCSDS 131.0-b Section 8 describes how slicing can be used to use LDPC codes with transfer frames up to the CCSDS limit (currently 524,288 bits for USLP and 16,384 bits for AOS) using slicing.

E. LunaNet proximity services should be available on both Left-Hand Circularly Polarized (LHCP) and Right-Hand Circularly Polarized (RHCP) waveforms to use spectrum allocations most efficiently. It is therefore recommended that LNSP relay vehicles be capable of switching to either polarization, or capable of providing simultaneous service on both polarizations (e.g., dual polarization). Some user missions may choose to operate with dual polarization, although that scenario is not explicitly discussed in this specification. The AFS service (PFS5) operates on a single polarization as defined in [AD1]. The MAR signal service (PRS5) has not been fully defined, including polarization.

B.I.I SINGLE ACCESS LNSP-USER PROXIMITY INTERFACES

The following notes apply to particular Single Access LNSP-User Proximity signal formats, with the notes referred to in the signal specifications in the following subsections.

[1] S-band is primarily intended for tracking, telemetry, and command (TT&C) data. The standard maximum bandwidth for non-spread spectrum S-band signals is limited to up to 5 MHz to allow systems to operate efficiently, and the maximum symbol and chip rates specifications are made in accordance with this standard limitation. In the interest of interoperability, all LNSPs should be capable of meeting the rate and subcarrier ranges specified here. However, this specification does not prohibit users from requesting wider bandwidths and capabilities beyond these ranges, assuming that they can acquire spectrum authorization and find service providers capable of the requested service.

[2] NRZ-L should be used for code symbols unless explicitly stated otherwise. NRZ-L is selected as the use of differential encoding (e.g., NRZ-M) would double decoding errors (one wrong level leads to two wrong transitions). See CCSDS 401-B Sections 2.4.2 and 2.4.11.

[3] Filtering is typical and recommended for BPSK signals. Users may choose to not filter BPSK signals in some situations, and LNSPs should be capable of accommodating that request. As a minimum for interoperability, LNSPs should have the capability to provide root raised cosine filtering. Users should understand that when choosing other filtering options, there may be increased losses due to unmatched filtering. LNSPs may choose to implement additional filtering types for user flexibility.

[4] See CCSDS 131.0-B- Section 7.4 for LDPC 1/2, 2/3, and 4/5.

[5] See CCSDS 131.0-B- Section 7.3 for LDPC 7/8.

[6] LDPC codes can be used with transfer frames up to the CCSDS limit (currently 524,288 bits for USLP and 16,384 bits for AOS) using slicing.

[7] All transfer frames shall be either AOS or USLP.

[8] The most recent version of the applicable standard shall be used, unless stated otherwise.

[9] PCM/PM (PFS1b/PRS1b) can also be supported with NRZ-L data format. It is expected that LNSPs should offer this capability, and the choice is left to users whether to utilize Bi-Phase-L or NRZ-L. Note that use of NRZ-L for this modulation is not currently discussed in CCSDS 401.0-B.

[10] The modulation index ranges provided here are a recommendation to ensure minimum interoperability of LNSPs. Users may request modulation index ranges outside this range, assuming they can get appropriate approvals and find an LNSP with the capability to service them.

[11] The use of simultaneous ranging with data requires consideration on the interaction between the carrier, data signal, and ranging signal. The ECSS Radio Frequency and Modulation handbook, ECSS-E-ST-50-05C Rev 2 Section 6.1.6 provides a useful rule-of-thumb: the combined peak modulation index (sum of data and ranging modulation indices) should not exceed 1.75 radians. The LunaNet interoperability specification does not prohibit violation of this rule, but it is strongly recommended to consider the performance of simultaneous ranging and data transmission in such circumstances.

[12] Applicable documents for some signals are to be determined. Standards development and coordination for lunar proximity communications is an ongoing effort. Future coordination with CCSDS to clarify these applications is planned.

[13] Several of the CCSDS recommendations within this section are currently written regarding Space-to-Earth and Earth-to-Space links. Despite the use of Earth focused language in the existing standards, these standards are applicable to the LunaNet specifications where cited.

[14] In some cases, the CCSDS standard specifically refer to usage for telemetry or telecommand but not both. The LunaNet specifications are symmetric in the return and forward directions, and therefore sometimes apply telemetry standards to telecommand links and vice-versa. This discrepancy between CCSDS recommendations and LunaNet specifications is realized and future clarification in coordination with CCSDS will be provided.

[15] For high throughput K-band links, higher order modulations and coding schemes are recommended to maximize bandwidth efficiency. Bandwidth efficient modulation and coding schemes are being investigated for LunaNet implementation.

Table B-1: PFS1a - Proximity Forward S-Band Data Only

PFS1a - Proximity Forward S-Band Data Only		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	See CCSDS 401.0-B Section 2.2.8 and 2.3.2 for explanation of BPSK. [1] [2] [3]
Polarization	LHCP and/or RHCP	
Symbol Rate	2 ksps ≤ Rs ≤ 2.048 Msps	
Modulation	Filtered BPSK	
Radiometric Ranging Options	No	-
Coding and Framing	Symbol Rate 0.002 to 1.0Msps • LDPC r=½ (2048, 1024) • Uncoded, Message Size 16,384 bits Symbol Rate 1.0 to 2.0 Msps • LDPC 1/2 (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-2: PFS1b - Proximity Forward S-Band Medium Rate w/ Ranging

PFS1b - Proximity Forward S-Band Medium Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. See CCSDS 401.0-B Section 2.2.7 for explanation of PCM/PM/bi-phase-L. [1] [9] [10] [11]
Polarization	LHCP and/or RHCP	
Symbol Rate	48 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM/bi-phase-L Data Modulation Index: 0.2 to 1.4 radians (peak)	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.4 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (2048, 1024) • LDPC 2/3 (6144, 4096) • Convolutional, r=1/2, k=7 • Uncoded, Message Size 16,384 bits [TBD]	[4] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[8] [12]

Table B-3: PFS1c - Proximity Forward S-Band Low-Rate w/ Ranging

PFS1c - Proximity Forward S-Band Low-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. [1] [10] [11]
Polarization	LHCP and/or RHCP	
Symbol Rate	0.5 ksps ≤ Rs ≤ 48 ksps Subcarrier Freq. (Sine): 4*Rs (or 8 kHz minimum)	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (peak)	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.4 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (2048, 1024)	[4] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[8] [12]

Table B-4: PFS1d - Proximity Forward S-Band High-Rate Data Only

PFS1d - Proximity Forward S-Band High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	See CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK and GMSK. This signal allows higher data rates with bandwidth efficiency. [1] [13] [14]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (2048, 1024) • LDPC ½ (8192, 4096) • LDPC 2/3 (6144, 4096) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits [TBD]	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8] [12]

Table B-5: PFS1e - Proximity Forward S-Band High-Rate w/ Ranging

PFS1e - Proximity Forward S-Band High-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	See CCSDS 401.0-B- Section 2.4.22A for an explanation of GMSK+PN. To be recommended for S-band Lunar Proximity. Allows bandwidth efficient higher data rates with simultaneous ranging [1] [13] [14]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	GMSK+PN Ranging	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (2048, 1024) • LDPC ½ (8192, 4096) • LDPC 2/3 (6144, 4096) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8] [12]

Table B-6: PRS1a - Proximity Return S-Band Data Only

PRS1a - Proximity Return S-Band Data Only		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	See CCSDS 401.0-B Section 2.3.2 for explanation of BPSK. [1] [2] [3] [13]
Polarization	LHCP and/or RHCP	
Symbol Rate	2 ksps ≤ Rs ≤ 2.048 Msps	
Modulation	Filtered BPSK	
Radiometric Ranging Options	No	-
Coding and Framing	Symbol Rate 0.002 to 1.0Msps • LDPC r=½ (2048, 1024) • Uncoded, Message Size 16,384 bits Symbol Rate 1.0 to 2.0 Msps • LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-7: PRS1b - Proximity Return S-Band Medium Rate w/ Ranging

PRS1b - Proximity Return S-Band Medium Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. See CCSDS 401.0-B Sections 2.4.7 and 2.4.15A for explanation of PCM/PM/bi-phase-L. [1] [9] [10] [11] [13] [14]
Polarization	LHCP and/or RHCP	
Symbol Rate	48 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM/bi-phase-L Data Modulation Index: 0.2 to 1.4 radians (peak)	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.0 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (2048, 1024) • LDPC 2/3 (6144, 4096) • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits [TBD]	[4] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[8] [12]

Table B-8: PRS1c - Proximity Return S-Band Low-Rate w/ Ranging

PRS1c - Proximity Return S-Band Low-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. See CCSDS 401.0-B Sections 2.2.4, 2.4.3, and 2.4.7 for explanation of PCM/PSK/PM. [1] [10] [11] [13] [14]
Polarization	LHCP and/or RHCP	
Symbol Rate	0.5 ksps ≤ Rs ≤ 48 ksps Subcarrier Freq. (Sine): 4*Rs (or 8 kHz minimum)	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (peak)	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.0 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (2048, 1024)	[4] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[8] [12]

Table B-9: PRS1d - Proximity Return S-Band High-Rate Data Only

PRS1d - Proximity Return S-Band High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	See CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK and GMSK. Allows for higher data rates with bandwidth efficiency. [1] [13]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (2048, 1024) • LDPC ½ (8192, 4096) • LDPC 2/3 (6144, 4096) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits [LNIS-TBR-4012]	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8] [12]

Table B-10: PRS1e - Proximity Return S-Band High-Rate w/ Ranging

PRS1e - Proximity Return S-Band High-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	See CCSDS 401.0-B Section 2.4.22A for an explanation of GMSK+PN. To be recommended for S-band Lunar Proximity. Allows bandwidth efficiency higher data rates with simultaneous ranging [1] [13]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	GMSK+PN Ranging	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (2048, 1024) • LDPC ½ (8192, 4096) • LDPC 2/3 (6144, 4096) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8] [12]

Table B-11: PFK1 - Proximity Forward K-band Data Only

PFK1 - Proximity Forward K-band Data Only		
Parameter	**Description**	**Notes**
Frequency Range	23.15-23.55 GHz	See CCSDS 401.0-B Section 2.3.2 for explanation of BPSK. Allows a simplified forward service on K-band for needs not requiring very high data rates. [13] [14]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ 2.048 Msps {TBR}	
Modulation	BPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 2/3 (24576, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-12: PFK2 - Proximity Forward K-band Variable Coding and Modulation

PFK2 - Proximity Forward K-band Variable Coding and Modulation		
Parameter	**Description**	**Notes**
Frequency Range	23.15-23.55 GHz	See CCSDS 401.0-B Section 2.4.23 and CCSDS 431.1-B for explanation of DVB-S1 and SCCC VCM methods. LDPC-VCM is not yet a formal CCSDS standard. Allows high data throughputs with spectrally efficient VCM schemes. [13] [14] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ {TBD} Msps	
Modulation	DVB-S2 or SCCC or LDPC-VCM	
Radiometric Ranging Options	No	
Coding and Framing	TBD	-
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 131.3-B CCSDS 431.1-B CCSDS 131.2-B	[8]

Table B-13: PFK3 - Proximity Forward K-band High-Rate Data Only

PFK3 - Proximity Forward K-band High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	23.15-23.55 GHz	See CCSDS 401.0-B Section 2.4.21A for explanation of Filtered OQPSK and GMSK. Allows spectrally efficient high data throughputs with simpler implementation than VCM. [13] [14] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ {TBD}Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 2/3 (24576, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-14: PFK4 - Proximity Forward K-band High-Rate Data w/ Ranging

PFK4 - Proximity Forward K-band High-Rate Data w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	23.15-23.55 GHz	See CCSDS 401.0-B- Section 2.4.22A for explanation of GMSK+PN. To be recommended for K-band Lunar Proximity. Allows simultaneous ranging on K-band signals. [10] [11] [13] [14] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1.5 Msps ≤ Rs ≤ {TBD} Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 2/3 (24576, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-15: PRK1 - Proximity Return K-band Data Only

PRK1 - Proximity Return K-band Data Only		
Parameter	**Description**	**Notes**
Frequency Range	27.0-27.5 GHz	See CCSDS 401.0-B Section 2.3.2 for explanation of BPSK. Allows a simplified return service on K-band for needs not requiring very high data rates. [13] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ 2.048 Msps	
Modulation	BPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 2/3 (24576, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4][5][6][7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-16: PRK2 - Proximity Return K-band Variable Coding and Modulation

PRK2 - Proximity Return K-band Variable Coding and Modulation		
Parameter	**Description**	**Notes**
Frequency Range	27.0-27.5 GHz	See CCSDS 401.0-B Section 2.4.23 and CCSDS 431.1-B for explanation of DVB-S1 and SCCC VCM methods. LDPC-VCM is not yet a formal CCSDS standard. Allows high data throughputs with spectrally efficient VCM schemes. [13] [14] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ {TBD} Msps	
Modulation	DVB-S2 or SCCC or LDPC-VCM	
Radiometric Ranging Options	No	
Coding and Framing	TBD	-
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 131.3-B CCSDS 431.1-R CCSDS 131.2-B	[8]

Table B-17: PRK3 - Proximity Return K-band High-Rate Data Only

PRK3 - Proximity Return K-band High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	27.0-27.5 GHz	See CCSDS 401.0-B Section 2.4.17A. Allows spectrally efficient high data throughputs with simpler implementation than VCM. [13] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1 Msps ≤ Rs ≤ {TBD}Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 2/3 (24576, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

Table B-18: PRK4 - Proximity Return K-band High-Rate Data w/ Ranging

PRK4 - Proximity Return K-band High-Rate Data w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	27.0-27.5 GHz	See CCSDS 401.0-B- Section 2.4.22A for explanation of GMSK+PN. To be recommended for K-band Lunar Proximity. Allows simultaneous ranging on K-band signals. [13] [14] [15]
Polarization	LHCP and/or RHCP	
Symbol Rate	1.5 Msps ≤ Rs ≤ {TBD} Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 2/3 (24576, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136) • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[8]

B.I.II SPREAD SPECTRUM LNSP-USER PROXIMITY INTERFACES

The following general notes regard the development of the spread spectrum signals:

A. The option to use non-regenerative ranging in the 415.1-B book has been proposed and is being worked on at CCSDS.

B. The intent of unbalanced return in the 415.1-B book was for higher science return data rate on one channel. These concepts are superseded by CCSDS virtual channels, where data rates of telemetry and science are controlled by the frame rates of the channels. Single data channel balanced QPSK is recommended for the lunar proximity return links.

The following notes apply to particular spread spectrum LNSP-user proximity link signal formats, with the notes referred to in the signal specifications in the following subsections:

[1] Standard maximum bandwidth for spread spectrum S-band signal is 6.16 MHz. This allows a chip rate of ~3 Mcps.

[2] See CCSDS 131.0-B Section 7.4 for LDPC 1/2, 2/3, and 4/5.

[3] LDPC codes can be used with transfer frames up to the CCSDS limit (currently 524,288 bits for USLP and 16,384 bits for AOS) using slicing.

[4] All transfer frames shall be either AOS or USLP

[5] The most recent version of the applicable standard shall be used, unless stated otherwise.

[6] Applicable documents for some signals are to be determined. Standards development and coordination for lunar proximity communications is an ongoing effort. Future coordination with CCSDS to clarify these applications is planned.

Table B-19: PFS2 - Proximity Forward S-band Medium Rate w/ Ranging

PFS2 - Proximity Forward S-band Medium Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz Fixed frequency assignments are {TBD}	The intent of this signal is a medium data rate signal with spread spectrum PN ranging and user specific PN code. Differentiated from PFS5 in that PFS5 utilizes a relay specific PN code for navigation service. Allows for higher data rates than PFS5, and signal parameters could be modified to some extent for individual users. [1]
Polarization	LHCP and/or RHCP	
Symbol Rate	Symbol & Chip Rates are {TBD}	
Modulation	SS-BPSK CDMA (~3Mcps) or SS-UQPSK {TBD}	
Radiometric Ranging Options	Yes, details are {TBD}	
Coding and Framing	LDPC ½ (2048, 1024)	[2][3][4]
Applicable Documents	CCSDS 415.1-B CCSDS 131.0-B	[5][6]

Table B-20: PRS2 - Proximity Return S-Band Spread Spectrum

PRS2 - Proximity Return S-Band Spread Spectrum		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz Fixed frequency assignments are {TBD}	Intent is for a wide beam spread spectrum return intended for P2P links. Similar to PRS5 but allows for higher data rates (less spreading) and ranging. There is a possibility to support multiple users simultaneously, albeit much less than PRS5. Signal parameters could also be modified for user specific needs {TBR}. [1]
Polarization	LHCP and/or RHCP	
Symbol Rate	Symbol & Chip Rates are {TBD}	
Modulation	SS-BPSK CDMA (~3Mcps) or SS-UQPSK {TBD}	
Radiometric Ranging Options	Yes, details are {TBD}	
Coding and Framing	LDPC ½ (2048, 1024)	[2] [3] [4]
Applicable Documents	CCSDS 415.1-B CCSDS 131.0-B	[5] [6]

Table B-21: PFS5 - Proximity Forward S-band Augmented Forward Signal (AFS)

Augmented Forward Signal (AFS) - PFS5 - Proximity Forward S-band		
Parameter	**Description**	**Notes**
Frequency Range	2483.5-2500 MHz, Fc = 2492.028 MHz	See Lunar Augmented Navigation System (LANS)
Symbol Rate	AFS Structure (Appendix C)	
Modulation	AFS Structure (Appendix C)	
Radiometric Ranging Options	Yes	
Coding and Framing	AFS Structure (Appendix C)	
Applicable Documents	AFS Structure (Appendix C)	

Table B-22: PRS5 - Proximity Return S-Band Multiple Access Return (MAR)

Multiple Access Return (MAR) - PRS5 - Proximity Return S-Band		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz Fixed frequency assignments are {TBD}	Low rate, many users multiple access return with ranging. [1]
Polarization	{TBD}	
Symbol Rate	Symbol & Chip Rates are {TBD}	
Modulation	SS-BPSK CDMA (~3Mcps) or SS-UQPSK {TBD}	
Radiometric Ranging Options	Yes, details are {TBD}	
Coding and Framing	TBD	[4]
Applicable Documents	CCSDS 415.1-B CCSDS 131.0-B	[5]

B.II LNSP – USER DWE INTERFACES

This section provides a summary of the signal definitions for the DWE links. DWE applies both to direct links between Earth and lunar surface and links between Earth and LunaNet relay nodes. In this document the special case of the link between a lunar relay orbiter and Earth station is identified as the "trunk link." A trunk link exists in both the forward and return directions.

The following general notes apply to DWE signals:

A. It is recommended that LNSPs and users utilize both Left-Hand Circularly Polarized (LHCP) and Right-Hand Circularly Polarized (RHCP) waveforms to use DWE spectrum allocations most efficiently. LNSPs and users should consider making DWE systems with switchable polarization, or dual polarization (utilizing both polarizations simultaneously to maximize efficiency).

B. Low-Density Parity Check (LDPC) codes are shown here in parenthetical (n, k) format, where n is the codeword length in bits and k is the information block length in bits. The code rate is also shown, although this can also be derived by $r = k/n$. CCSDS 131.0-b Section 7.3 describes the LDPC 7/8 (8160, 7136) code. CCSDS 231.0-b Section 4 describes the LDPC ½ (128, 64) and LDPC ½ (512, 256) codes. CCSDS 131.0-b Section 7.4 describes the remaining LDPC ½, LDPC 2/3, and LDPC 4/5 of various (n, k) values used in this specification. CCSDS 131.0-b Section 8 described how slicing can be used to use LDPC codes with transfer frames up to the CCSDS limit (currently 524,288 bits for USLP and 16,384 bits for AOS) using slicing.

The following notes apply to particular DWE link signal formats, with the notes referred to in the signal specifications in the following subsections:

[1] PCM/PM (XU1/XD1) can also be supported with NRZ-L data format. It is expected that LNSPs should offer this capability, and the choice is left to users whether to utilize Bi-Phase-L or NRZ-L. Note that use of NRZ-L for this modulation is not currently discussed in CCSDS 401.0-B.

[2] The modulation index ranges provided here are a recommendation to ensure minimum interoperability of LNSPs. Users may request modulation index ranges outside this range, assuming they can get appropriate approvals and find an LNSP with the capability to service them.

[3] The use of simultaneous ranging with data requires consideration on the interaction between the carrier, data signal, and ranging signal. The ECSS Radio Frequency and Modulation handbook, ECSS-E-ST-50-05C Rev 2 Section 6.1.6 provides a useful rule-of-thumb: the combined peak modulation index (sum of data and ranging modulation indices) should not exceed 1.75 radians. This interoperability specification does not prohibit violation of this rule, but it is strongly recommended to consider the performance of simultaneous ranging and data transmission in such circumstances.

[4] The 4 Mcps chip rate is based on the standard maximum allowed bandwidth of 10 MHz for X-band Space Research.

[5] See CCSDS 231.0-B – for description of LDPC short codes (128, 64) & (512, 256).

[6] See CCSDS 131.0-B- Section 7.4 for a description of LDPC 1/2, 2/3, and 4/5.

[7] See CCSDS 131.0-B- Section 7.3 for a description of LDPC 7/8.

[8] LDPC codes can be used with transfer frames up to the CCSDS limit (currently 524,288 bits for USLP, 16,384 bits for AOS) using slicing. See CCSDS 131.0-B- Chapter 8 and Chapter 11.

[9] All transfer frames shall be either AOS or USLP.

[10] The most recent version of the applicable standard shall be used, unless stated otherwise.

[11] Applicable documents for some signals are to be determined. Standards development and coordination for lunar proximity communications is an ongoing effort. Future coordination with CCSDS to clarify these applications is planned. In some cases, the CCSDS standard specifically refer to usage for telemetry or telecommand but not both. The LunaNet specifications are symmetric in the return and forward directions, and therefore sometimes apply telemetry standards to telecommand links and vice-versa. This discrepancy between CCSDS recommendations and LunaNet specifications is realized and future clarification in coordination with CCSDS will be provided.

[12] For high throughput K-band trunk links (> 200 Msps), higher order modulations and coding schemes are recommended to maximize bandwidth efficiency. VCM or a subset of the codes in the VCM standard can be considered.

Table B-23: XU1 - X-band Uplink Medium Rate w/ Ranging

XU1 - X-band Uplink Medium Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	7190-7235 MHz	See CCSDS 401.0-B Section 2.2.7 for explanation of PCM/PM/bi-phase-L. Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. [1] [2] [3] [4]
Polarization	LHCP and/or RHCP	
Symbol Rate	64 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM/bi-phase-L Data Modulation Index: 0.2 to 1.4 radians (Peak)	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.4 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (512, 256) • LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[5] [6] [7] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 231.0-B CCSDS 401.0-B CCSDS 414.1-B	[10]

Table B-24: XU2 - X-band Uplink High-Rate w/ Ranging

XU2 - X-band Uplink High-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	7190-7235 MHz	See CCSDS 401.0-B- Section 2.4.22A for an explanation of GMSK+PN Allows bandwidth efficient higher data rates with simultaneous ranging.
Polarization	LHCP and/or RHCP	
Symbol Rate	150 ksps ≤ Rs ≤ 1 Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6] [7] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[10] [11]

Table B-25: XU3 - X-band Uplink Low-Rate w/ Ranging

XU3 - X-band Uplink Low-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	7190-7235 MHz	See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. [2] [3] [4] .
Polarization	LHCP and/or RHCP	
Symbol Rate	0.5 ksps ≤ Rs ≤ 64 ksps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak)	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.4 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (512, 256) • LDPC ½ (2048, 1024) • Uncoded, Message Size 16,384 bits	[5] [6] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 231.0-B CCSDS 401.0-B CCSDS 414.1-B	[10]

Table B-26: XU4 - X-band Uplink High-Rate Data Only

XU4 - X-band Uplink High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	7190-7235 MHz	See CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK and GMSK. Allows for higher data rates with bandwidth efficiency.
Polarization	LHCP and/or RHCP	
Symbol Rate	128 ksps ≤ Rs ≤ 10 Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6] [7] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[10] [11]

Table B-27: XD1 - X-band Downlink Medium Rate w/ Ranging

XD1 - X-band Downlink Medium Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	8450-8500 MHz	See CCSDS 401.0-B Sections 2.2.7 and 2.4.7 for explanation of PCM/PM/bi-phase-L Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. [1] [2] [3] [4]
Polarization	LHCP and/or RHCP	
Symbol Rate	64 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM/bi-phase-L Data Modulation Index: 0.2 to 1.4 radians (Peak)	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.0 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6] [7] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[10] [11]

Table B-28: XD2 - X-band Downlink High-Rate w/ Ranging

XD2 - X-band Downlink High-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	8450-8500 MHz	See CCSDS 401.0-B- Section 2.4.22A for an explanation of GMSK+PN Allows bandwidth efficient higher data rates with simultaneous ranging.
Polarization	LHCP and/or RHCP	
Symbol Rate	150 ksps ≤ Rs ≤ 1 Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6] [7] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[10] [11]

Table B-29: XD3 - X-band Downlink Low-Rate w/ Ranging

XD3 - X-band Downlink Low-Rate w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	8450-8500 MHz	See CCSDS 401.0-B Sections 2.2.4, 2.4.3, and 2.4.7 for explanation of PCM/PSK/PM. Presence of residual carrier aids demodulation (e.g., large doppler dynamics scenarios) and allows simultaneous ranging. [2] [3] [4]
Polarization	LHCP and/or RHCP	
Symbol Rate	0.5 ksps ≤ Rs ≤ 64 ksps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak)	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.0 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (2048, 1024) • Uncoded, Message Size 16,384 bits	[6] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[10]

Table B-30: XD4 - X-band Downlink High-Rate Data Only

XD4 - X-band Downlink High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	8450-8500 MHz	See CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK and GMSK. Allows for higher data rates with bandwidth efficiency.
Polarization	LHCP and/or RHCP	
Symbol Rate	128 ksps ≤ Rs ≤ 10 Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6] [7] [8] [9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[10]

Table B-31: KU1 - K-band Uplink High-Rate Data Only

KU1 - K-band Uplink High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	22.55-23.15 GHz	See CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK and GMSK. Allows spectrally efficient high data throughputs with simpler implementation than VCM. [12]
Polarization	LHCP and/or RHCP	
Symbol Rate	2 Msps ≤ Rs ≤ 50 Msps {TBR}	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	Frame ranging [RD24, RD25]	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6][7][8][9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[10][11]

Table B-32: KU2 - K-band Uplink High Data w/ Ranging

KU2 - K-band Uplink High Data w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	22.55-23.15 GHz	See CCSDS 401.0-B- Section 2.4.22A for an explanation of ranging implementation of GMSK+PN To be recommended for K-band DWE. Allows simultaneous ranging on K-band signals. [2] [12]
Polarization	LHCP and/or RHCP	
Symbol Rate	2 Msps ≤ Rs ≤ 50 Msps {TBR}	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 (8160, 7136)	[6][7][8][9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[10] [11]

Table B-33: KD1- K-band Downlink High-Rate Data Only

KD1 - K-band Downlink High-Rate Data Only		
Parameter	**Description**	**Notes**
Frequency Range	25.5-27.0 GHz	See CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK and GMSK. Allows spectrally efficient high data throughputs with simpler implementation than VCM. [12]
Polarization	LHCP and/or RHCP	
Symbol Rate	2 Msps ≤ Rs ≤ 200 Msps {TBR}	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	Frame ranging [RD24, RD25]	
Coding and Framing	• LDPC ½ (32768, 16384) • LDPC 4/5 (20480, 16384) • LDPC 7/8 Rate (8160, 7136)	[6][7][8][9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B	[10]

Table B-34: KD2 - K-band Downlink High Data w/ Ranging

KD2 - K-band Downlink High Data w/ Ranging		
Parameter	**Description**	**Notes**
Frequency Range	25.5-27.0 GHz	See CCSDS 401.0-B- Section 2.4.22A for an explanation of the ranging implementation of GMSK+PN. To be recommended for K-band DWE. Allows simultaneous ranging on K-band signals. [2][12]
Polarization	LHCP and/or RHCP	
Symbol Rate	2 Msps ≤ Rs ≤ 200 Msps {TBR}	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ Rate (32768, 16384) • LDPC 4/5 Rate (20480, 16384) • LDPC 7/8 Rate (8160, 7136)	[6][7][8][9]
Applicable Documents	CCSDS 131.0-B CCSDS 401.0-B CCSDS 414.1-B	[10][11]

B.III LNSP-USER CONTINGENCY INTERFACES

Contingency mode signals are those used during off nominal or emergency states, when power is limited, or antenna pointing is compromised.

The following general notes apply to the contingency mode signals:

A. Fixed symbol rates are used for contingency mode signals to further promote interoperability and standardization, whereas in standard Proximity and DWE signals modes more flexibility is given to user platforms. The rationale for this decision is a reduced need for flexibility of symbol rate in the contingency mode signals, and a greater need for interoperability and standardization to promote availability of contingency mode support. Some flexibility is given by providing two options for each contingency interface, a very low symbol rate or a slightly higher symbol rate.

B. A subcarrier signal is used for contingency mode operations in order to support carrier tracking and aid demodulation. These signals can be used as data only, ranging only, or data and ranging simultaneously. When doing data and ranging simultaneously (especially in contingency mode operations), careful consideration must be made regarding the modulation depth of the ranging and data signals and the interaction between them. The footnotes provide further guidance.

C. Low-Density Parity Check (LDPC) codes are shown here in parenthetical (n, k) format, where n is the codeword length in bits and k is the information block length in bits. The code rate is also shown, although this can also be derived by $r = k/n$. CCSDS 231.0-b Section 4 describes the LDPC ½ (128, 64) and LDPC 1/2 (512, 256) codes, which are used for the contingency mode signals described below.

D. In addition to the modes shown below, LNSPs should be capable of disabling FEC on any of the nominal mode's signals specified in User Proximity interfaces and DWE interfaces as a contingency mode option.

The following notes apply to particular User Contingency signal formats, with the notes referred to in the signal specifications in the following subsections.

[1] The modulation index ranges provided here are a recommendation to ensure minimum interoperability of LNSPs. Users may request modulation index ranges outside this range, assuming they can get appropriate approvals and find an LNSP with the capability to service them.

[2] The use of simultaneous ranging with data requires consideration on the interaction between the carrier, data signal, and ranging signal. The ECSS Radio Frequency and Modulation handbook, ECSS-E-ST-50-05C Rev 2 Section 6.1.6 provides a useful rule-of-thumb: the combined peak modulation index (sum of data and ranging modulation indices) should not exceed 1.75 radians. This interoperability specification does not prohibit violation of this rule, but it is strongly recommended to consider the performance of simultaneous ranging and data transmission in such circumstances.

[3] See CCSDS 231.0-B for description of LDPC short codes 1/2 (128, 64) and ½ (512, 256).

[4] LDPC codes can be used with transfer frames up to the CCSDS limit (currently 524,288 bits for USLP, 16,384 bits for AOS) using slicing. See CCSDS 131.0-B Chapter 8 and Chapter 11.

[5] All transfer frames shall be either AOS or USLP

[6] The most recent version of the applicable standard shall be used, unless stated otherwise.

[7] Applicable documents for some signals are to be determined. Standards development and coordination for lunar proximity communications is an ongoing effort. Future coordination with CCSDS to clarify these applications is planned. In some cases, the CCSDS standard specifically refer to usage for telemetry or telecommand but not both. The LunaNet specifications are

symmetric in the return and forward directions, and therefore sometimes apply telemetry standards to telecommand links and vice-versa. This discrepancy between CCSDS recommendations and LunaNet specifications is realized and future clarification in coordination with CCSDS will be provided.

Table B-35: PFC1a - Proximity Forward S-band Contingency

PFC1a - Proximity Forward S-band Contingency		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. Lowest rate used for very weak signal links. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	15.625 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.4 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (128, 64)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6][7]

Table B-36: PFC1b - Proximity Forward S-band Contingency

PFC1b - Proximity Forward S-band Contingency		
Parameter	**Description**	**Notes**
Frequency Range	2025-2110 MHz	See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. Higher rate to provide flexibility for cislunar space operations. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	250 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.4 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ Rate (512, 256)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6][7]

Table B-37: PRC1a - Proximity Return S-band Contingency

PRC1a - Proximity Return S-band Contingency		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	See CCSDS 401.0-B Sections 2.2.4, 2.4.3, and 2.4.7 for explanation of PCM/PSK/PM. Lowest rate used for very weak signal links. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	15.625 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.0 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (128, 64)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6][7]

Table B-38: PRC1b - Proximity Return S-band Contingency

PRC1b - Proximity Return S-band Contingency		
Parameter	**Description**	**Notes**
Frequency Range	2200-2290 MHz	See CCSDS 401.0-B Sections 2.2.4, 2.4.3, and 2.4.7 for explanation of PCM/PSK/PM. Higher rate to provide flexibility for cislunar space operations. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	250 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.0 radians (peak) Chip rate: up to 2.3 Mcps	
Coding and Framing	• LDPC ½ (512, 256)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6][7]

Table B-39: CU1 - X-band Uplink Contingency

CU1 - X-band Uplink Contingency		
Parameter	**Description**	**Notes**
Frequency Range	7190-7235 MHz	See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. Lowest rate typically used for deep space. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	15.625 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.4 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (128, 64)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6]

Table B-40: CU2 - X-band Uplink Contingency

CU2 - X-band Uplink Contingency		
Parameter	**Description**	**Notes**
Frequency Range	7190-7235 MHz	See CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. Higher rate to provide flexibility for cislunar space operations. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	250 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging on carrier Ranging Modulation Index: 0.2 to 1.4 radians (peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (512, 256)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6]

Table B-41: CD1 - X-band Downlink Contingency

CD1 - X-band Downlink Contingency		
Parameter	**Description**	**Notes**
Frequency Range	8450-8500 MHz	See CCSDS 401.0-B Sections 2.2.4, 2.4.3, and 2.4.7 for explanation of PCM/PSK/PM. Lowest rate typically used for deep space. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	20 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.0 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (128, 64)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6] [7]

Table B-42: CD2 - X-band Downlink Contingency

CD2 - X-band Downlink Contingency		
Parameter	**Description**	**Notes**
Frequency Range	8450-8500 MHz	See CCSDS 401.0-B Sections 2.2.4, 2.4.3, and 2.4.7 for explanation of PCM/PSK/PM. Higher rate to provide flexibility for cislunar space operations. [1][2]
Polarization	LHCP and/or RHCP	
Symbol Rate	250 sps	
Modulation	PCM/PSK/PM+NRZ-L Data Modulation Index: 0.2 to 1.8 radians (Peak) Subcarrier Freq. (Sine): 16 kHz	
Radiometric Ranging Options	PN Ranging Ranging Modulation Index: 0.2 to 1.0 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (512, 256)	[3][4][5]
Applicable Documents	CCSDS 401.0-B CCSDS 231.0-B	[6] [7]

APPENDIX C NAVIGATION PARAMETERS

The AFS service is enabled using a spread spectrum signal structure similar to the ones used in GNSS, allowing significant reuse of GNSS spaceborne receivers. The signal will be broadcast in the 2483.5-2500 MHz frequency range, being the band designed for radionavigation in recommendation SFCG 32-2R5 from the SFCG CDMA allows different LNSP sources to provide the AFS service simultaneously at a single and common S-band frequency, and individual, orthogonal PN codes will be assigned to each LNSP node implementing this service. [AD1] will identify the method to assign PN codes to LNSP nodes.

Modulations adopted will be in line with current GNSS signals, by utilizing Bi-Phase Shift Keying (BPSK) modulations. Two channels are identified, one in-phase (I) and one in quadrature phase (Q). The I-channel is intended to facilitate acquisition and navigation capabilities and serve as a data channel. The I-channel will consist of a BPSK (1) modulation, utilizing a spreading code at 1.023 Mcps. This data channel is used to disseminate LunaNet messages, carrying navigation, general access, alerts, and SAR information. The Q-channel is intended to provide higher accuracy PNT services, in the form of a pilot channel, carrying no data and employing different PN codes to maximize cross-correlation properties. Q-channel will employ BPSK (5) modulation with a spreading code at 5.115Mcps. Chip-rates for both channels will be synchronized with each other and coherently related to a mutual carrier frequency reference.

To transmit a carrier center frequency of 2492.028 MHz, the reference clock can be at 1.023MHz utilizing a reference clock multiplier of 2436. The detailed definition of the signal is provided in the LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal [AD1] document. Note that the signal structure and the LANS service in section 3.2.2 will be used for all LunaNet nodes broadcasting the AFS/PFS5 signal.

Messages that will be transmitted as part of AFS on PFS5 are identified in Appendix D and as detailed in [AD1].

Each LNSP shall ensure the AFS maintains Signal-In-Space-Errors (SISE) within the requirement specified in Table C-1 within the defined service volume.

The SISE is defined as the instantaneous difference between the position, velocity, and time of a LunaNet node as broadcasted by that node's navigation message and the true satellite PVT respectively expressed in the lunar reference system and the lunar time system standard [AD5].

This definition is independent of the orbital characteristics of each LunaNet node and establishes an upper bound on the error experienced at user level that is the result of the projection of the SISE onto the user-satellite direction [RD 25]. This allows users to derive reliable navigation solutions at a dependable level when using LANS from different LNSPs. The SISE consists of a combination of errors that are the responsibility of the LNSPs, such as:

[1] LNSP ephemeris uncertainties or errors in the orbital products tendered to users, as represented in the lunar reference frame.
[2] LNSP timing errors due to time knowledge uncertainties, inaccurate clock correction information conveyed to users, or misalignments of time with the signal realization.
[3] Uncalibrated or unknown LNSP group delays due to code phase offsets, antenna phase offsets and variations, unaccounted transmit path delays and variations, code-to-code incoherency, code-to-carrier incoherency, etc.

The SISE can be expressed for convenience in two parts:

1. Signal-In-Space Error for positioning (SISE pos)

$$SISE_{pos} = \sqrt{(x-\tilde{x})^2 + (y-\tilde{y})^2 + (z-\tilde{z})^2 + (ct-c\tilde{t})^2}\,, \qquad \mathbf{1}$$

Where x, y, z, t are the true position and time, while the corresponding tilde parameters represent the values broadcasted in the navigation message.

2. Signal-In-Space Error for velocity (SISE vel):

$$SISE_{vel} = \sqrt{(\dot{x}-\tilde{\dot{x}})^2 + (\dot{y}-\tilde{\dot{y}})^2 + (\dot{z}-\tilde{\dot{z}})^2 + (c\dot{t}-c\tilde{\dot{t}})^2}\,, \qquad \mathbf{2}$$

Where $\dot{x}, \dot{y}, \dot{z}$ represents the velocity and $c\dot{t}$ the clock drift.

Table C-1: LNSP SISE

Error	Value
SISE pos	≤TBD m (95%) - Calculated as the 95th percentile of the time series of instantaneous SISE values over a TBD hours period.
SISE vel	≤TBD m/s (95%) - Calculated as the 95th percentile of the time series of instantaneous SISE values over a TBD hours period.

Table C-2: Proximity Link Supporting Signals

PNT Service ID	Services	Band-Direction	S-Forward							Ka-Forward	Ka-Forward	Ka-Forward	Ka-Forward
		Interop Signal ID	PFS1a	PFS1b	PFS1c	PFS1d	PFS1e	PFS2	PFS5	PFK1	PFK2	PFK3	PFK4
1wDRef	1-Way FWD Doppler Reference		O	O	O	O	O	O	X	O	O	O	O
1wRTRef	FWD Pseudo-Range and Timing Reference			TBW	TBW		TBW	TBW	X	TBW	TBW	TBW	TBW
1wDMeas	1-Way RTN Doppler Measurement												
1wRTMeas	RTN Pseudo-Range Measurement												
2wDMeas	2-Way Doppler Measurement		O	O	O	O	O	O		TBW	TBW	TBW	TBW
2wRMeas	2-Way Range Measurement			O	O		O	O		TBW	TBW	TBW	TBW
2wD-XPND	2-Way Coherent Doppler Transponder		O	O	O	O	O	O		TBW	TBW	TBW	TBW
2wNRR-XPND	Non-Regenerative Range Transponder			O	O		O						
2wRR-XPND	Regenerative Range Transponder			TBW	TBW		O	O					O
TRef	FWD Time Transfer			TBW	TBW		TBW	TBW	X	TBW	TBW	TBW	TBW
LANS	Lunar Augmented Navigation Service (LANS)								X				

[1] "TBW" indicates this item is to be worked.
[2] "O" indicates the signal supports the ability to provide the service.
[3] "X" indicates it is mandatory for the signal to provide the service.

Table C-3: Proximity Link Supporting Signals

PNT Service ID	Services	Band-Direction	S-Return							Ka-Return	Ka-Return	Ka-Return	Ka-Return
		Interop Signal ID	PRS1a	PRS1b	PRS1c	PRS1d	PRS1e	PRS2	PRS5	PRK1	PRK2	PRK3	PRK4
1wDRef	1-Way FWD Doppler Reference												
1wRTRef	FWD Pseudo-Range and Timing Reference												
1wDMeas	1-Way RTN Doppler Measurement		O	O	O	O	O	O	O	O	O	O	O
1wRTMeas	RTN Pseudo-Range Measurement				TBW		TBW	TBW	TBW	TBW	TBW	TBW	TBW
2wDMeas	2-Way Doppler Measurement		O	O	O	O	O	O	TBW[1]	TBW	TBW	TBW	TBW
2wRMeas	2-Way Range Measurement							X		TBW	TBW	TBW	TBW
2wD-XPND	2-Way Coherent Doppler Transponder		O	O	O	O	O	O		TBW	TBW	TBW	TBW
2wNRR-XPND	Non-Regenerative Range Transponder			O	O		TBW						
2wRR-XPND	Regenerative Range Transponder			TBW	TBW		TBW	O					TBW
TRef	FWD Time Transfer												
LANS	Lunar Augmented Navigation Service (LANS)												

[1] "TBW" indicates this item is to be worked.
[2] "O" indicates the signal supports the ability to provide the service.
[3] "X" indicates it is mandatory for the signal to provide the service.
[4] “1” To provide the 2-way Doppler Measurement, PRS5 must be coherent with a PRFx signal which may be other than PRF5.

APPENDIX D LUNANET MESSAGES

D.I OVERVIEW OF MESSAGES

Messaging services provide a standard method for information to be transferred directly over a link layer service, a network layer service, or via dedicated message streams (e.g., AFS messages). These messaging services are utilized by protocols for PNT services, network acquisition, space weather alerts, search and rescue, and other LunaNet services. Standard messages are envisioned to be used across user proximity links, provider crosslinks, as well as DWE links.

At this time, the application of messages to the P2P links and crosslinks have not been fully defined. Thus, it is relevant to note that the particulars of the messages on these link types may differ slightly from those on the AFS.

LunaNet Detailed Message Definition Document (LNIS-TBD-AD0003) [AD3] will specify all message formats, content, parameters, and association with each service and/or signal. An overview is provided herein, starting with that lists the message ID, message title, and a brief description.

Table D-1: Message Identification

MSG ID	MSG Title	Description
MSG-G1	LunaNet Network Access Information	Identifies attributes needed to access network services. Informs users of basics applicable to LNSP nodes, such as services offered and bands, update rate of messages. May include other messages plus additional info, such as almanac, MLN Antenna Properties, H&S.
MSG-G2	Health and Safety	Health status of the service(s) provided by the LNSP node and is specific to the LNSP node. Health status of other LNSP nodes is provided as part of MSG-G5 MOrbit Almanac.
MSG-G3	MAntennaProperties	Information about the transmission antenna properties (e.g.: antenna offset from CG in body frame, articulating or static, proximity signal FOVs, attitude (3-axis, nadir, or other)). Default information can be specified in the standard. LNSP must identify default values of the antenna properties in their ICDs. If an LNSP is fully compliant with the default values in the ICDs this message might be omitted. On the contrary, if the LNSP is not compliant with the default specification, they shall disseminate this message. At the user level, this is transparent: the user will receive the messages and interpret them as needed.
MSG-G4	Sorbit Ephemeris & clock correction	Precise ephemeris, path delays, and clock corrections of the satellite that is transmitting the signal. This message will also contain (if required) the clock offset between the LNSP time to the lunar reference time. This is specific for PNT, not to be confused with MSG-G5 MOrbitAlmanac. The message will broadcast the parameters to be used in the orbital model defined in the LNSP-specific documentation (e.g., ICD).

Table D-2 provides the following information for each message transmitted via AFS.

MSG ID	MSG Title	Description
MSG-G5	MOrbit Almanac	Parameters of the orbital model (low accuracy model, ~km orbit position accuracy, ~m/s orbit velocity accuracy) of all the satellites in the LNSP constellation. This message will also (optionally, TBD) include the health status of the services provided by all the LNSP nodes.
MSG-G6	SOrbit Almanac	Parameters of the orbital model (low accuracy model on the order of km orbital position accuracy and m/s orbital velocity accuracy) of the LNSP node transmitting the signal.
MSG-G7	SOrbitState / Location	Location Service information to user, whether on surface or in orbit.
MSG-G8	Time of transmission	Time information provided at the defined edge of a synchronization symbol within the navigation message.
MSG-G9	Time and Frequency Synchronization (frame)	Time information provided to allow implementation of navigation services other than LANS or a dedicated CDMA signal.
MSG-G10	Maneuver	Announces a planned maneuver of an LNSP satellite to the users and network, or of a user to an LNSP for Location Service.
MSG-G11	SAttitude State/ Ephemeris	Attitude information of the satellite. This message could implement the parameters of an attitude model to allow the user to compute the current and future attitude of the transmitting satellite. Alternatively, a time series of already computed attitude information could be broadcast to the user.
MSG-G12	MAttitudeEphem	Attitude information of multiple satellites, e.g., the constellation of LNSP nodes.
MSG-G13	Observations	Information on metric tracking measurements (observations) performed by one entity that is forwarded to a separate entity.
MSG-G14	Conjunction	Announces a potential conjunction between lunar orbiters. This concept could be like the CCSDS standard for Conjunction Data Message exchanges.
MSG-G15	Maplet	Map information for specific selenographic sectors or seleno-global. Details to be worked on specific content; concepts include sector index ID, current versions, delta update information from reference to limit dissemination time.
MSG-G16	Map Comprehensive	Full high resolution digital elevation map for specific lunar surface selenographic sector(s).
MSG-G17	Ancillary info	Basic data required for PNT, for example reference frames, coordinate transformations, lunar potential models, lunar ephemeris, lunar orientation parameters, covariance, and state transition matrix.
MSG-S18	Search and Rescue Alert	Alert from Search and Rescue beacon.

MSG ID	MSG Title	Description
MSG-G5	MOrbit Almanac	Parameters of the orbital model (low accuracy model, ~km orbit position accuracy, ~m/s orbit velocity accuracy) of all the satellites in the LNSP constellation. This message will also (optionally, TBD) include the health status of the services provided by all the LNSP nodes.
MSG-G6	SOrbit Almanac	Parameters of the orbital model (low accuracy model on the order of km orbital position accuracy and m/s orbital velocity accuracy) of the LNSP node transmitting the signal.
MSG-G7	SOrbitState / Location	Location Service information to user, whether on surface or in orbit.
MSG-G8	Time of transmission	Time information provided at the defined edge of a synchronization symbol within the navigation message.
MSG-G9	Time and Frequency Synchronization (frame)	Time information provided to allow implementation of navigation services other than LANS or a dedicated CDMA signal.
MSG-S19	Acknowledge- of SAR - LvL1	Automatic acknowledge at the LNSP satellite level of receipt of a SAR beacon distress message. This does not mean the message has been processed by the SAR ground system.
MSG-S20	Acknowledge- of SAR - LvL2	Acknowledgement that the SAR beacon alert request has been correctly received at the control center and that a rescue operation has started (also called LunaSAR return message).
MSG-G21	User Message Request	Request by user for specific message.
MSG-G22	Acknowledge- of non-SAR MSG	Automatic acknowledge at the LNSP satellite level of receipt of a user request (non-SAR). Note that this is not the response to the request, but simply an acknowledgement of receipt.
MSG-G23	GNSS Augmentation	Augmentation information (e.g., satellites ephemeris) on Earth GNSS satellites to support the use of Earth GNSS signals by GNSS sensitive receivers in cislunar space.
MSG-G24	Detection Alert	Used to broadcast an alert that must be disseminated to the users.
MSG-G25	Science	Disseminates science-specific data.
MSG-G26	UIS Request	Request from user for services from an LNSP.
MSG-G27	UIS Response	Notification to user indicating response to the UIS Request.
MSG-G28	User Schedule Notice	Notification to user of upcoming service schedule that needs to be disseminated to ensure receipt prior to an upcoming P2P contact.
MSG-G29	FF Commands	Specific user commands or information needed rapidly by user, distributed via broadcast.

Under each PNT sub-service, a label is used to identify which category applies to that message/service combination within the available AFS bandwidth: F = Fundamental, meaning it shall be broadcasted by the

LNSP; O = Optional, meaning it might be broadcasted by the LNSP; and C = Comm, meaning it can be transmitted on AFS to facilitate LunaNet services. In Table D-2 below, fields that are grey with a dash indicate the fact that the message is not provided over the service link.

- **Periodicity**: “Periodic” means the message is transmitted at a regular cadence; “ad-hoc” means the message is sent only when needed or requested.
- **Cadence**: Identifies the time between consecutive transmission of periodic messages with the same message ID (e.g., MSG-Gx). Note: the message information may not be updated at this cadence, the actual data may be static on successive transmissions.
- **Latency**: Identifies the time between message generation/reception and message transmission. If marked N/A, there is no stringent requirement from an interoperability standpoint.

Table D-2: LANS / AFS Messages

					LANS via AFS							
				SERVICE	PNT				Detection		Network	
				SUB-SERVICE	1wDRef	1wRTRef	TRef	Nav-Supp	SAR	Alert	Net	Comm
	DESCRIPTION	Periodicity	Cadence	Latency	1-Way Doppler Reference	Pseudo-Range and Timing Reference	Time Transfer Reference	Supplemental Navigation Products	Search and Rescue	Alert Notice to User	Network Attributes	User Communication
Message ID	Message Title											
MSG-G1	LunaNet Network Access Information	Periodic (TBC)	TBD	TBD							F	
MSG-G2	Health and Safety	Periodic	1sec to 1min (TBC)	TBD							F	
MSG-G3	M Antenna Properties	TBD	N/A	TBD							O	
MSG-G4	S Orbit Ephemeris+Clock correction	Periodic	1sec to 5min	TBD	F	F	F					
MSG-G5	M Orbit Almanac	Periodic	1min to 20 min (TBC)	N/A				F				
MSG-G6	S Orbit Almanac	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G7	S OrbitState /Location	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G8	Time and Frequency Synchronization (fine)	Periodic	1-10 sec	ms to 1 sec	F	F	F					
MSG-G9	Time and Frequency Synchronization (frame)	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G10	Maneuver	ad-hoc	1min thru maneuver	advance thru maneuver				O				
MSG-G11	S Attitude State/Ephemeris	Ad-hoc	N/A	TBD				O				
MSG-G12	M AttitudeEphem	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G13	Observations	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G14	Conjunction	Ad-hoc	N/A	TBD time before conjunction				O				
MSG-G15	Maplet	Ad-hoc	N/A	N/A				O				
MSG-G16	Map Comprehensive	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G17	Ancillary info	Ad-hoc	N/A	N/A				O				
MSG-S18	Search and Rescue Alert	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-S19	Acknowledge - of SAR - LvL1	Ad-hoc	N/A	reception at LNSP node					F			
MSG-S20	Acknowledge - of SAR - LvL2	Ad-hoc / periodic (TBD)	N/A	1-10 min (TBC) from LunaNet constellation reception of the SAR Operations Center response					F			
MSG-G21	User Message Request	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G22	Acknowledge - of non-SAR MSG	Ad-hoc	N/A	request reception at LNSP node								O
MSG-G23	GNSS Augmentation	Periodic	TBD	TBD				O				
MSG-G24	Detection Alert	Ad-hoc / periodic (TBD)	N/A	1-10 min (TBC) from reception of the alert						O		
MSG-G25	Science	TBD	TBD	TBD								C
MSG-G26	UIS Request	N/A	N/A	N/A	--	--	--	--	--	--	--	--
MSG-G27	UIS Response	Ad-hoc	N/A	TBD								C
MSG-G28	User Schedule Notice	Ad-hoc	N/A	TBD								C
MSG-G29	FF Commands	Ad-hoc	N/A	TBD								C