LunaNet Interoperability Specification Document

Version 5

Preface

LunaNet Interoperability Specification (LNIS)

The set of documents that comprise the LunaNet Interoperability Specification (LNIS) defines a framework of mutually agreed-upon standards, protocols, and interface specifications that enable interoperability. LunaNet is envisioned as a network of cooperating networks (network of networks, akin to the terrestrial Internet) upon which providers can deliver communications, position, navigation, and timing, and other services for users in transit to, around, and on the Moon.

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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, position, navigation, and timing (PNT), 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. The evolving instantiation of LunaNet is comprised of LunaNet Service Providers (LNSPs) providing services to lunar users and their Earth-based systems over terrestrial interfaces, Direct with Earth (DWE) RF or optical links, links with lunar orbiting platforms, or links with lunar surface elements (see Figure 1).

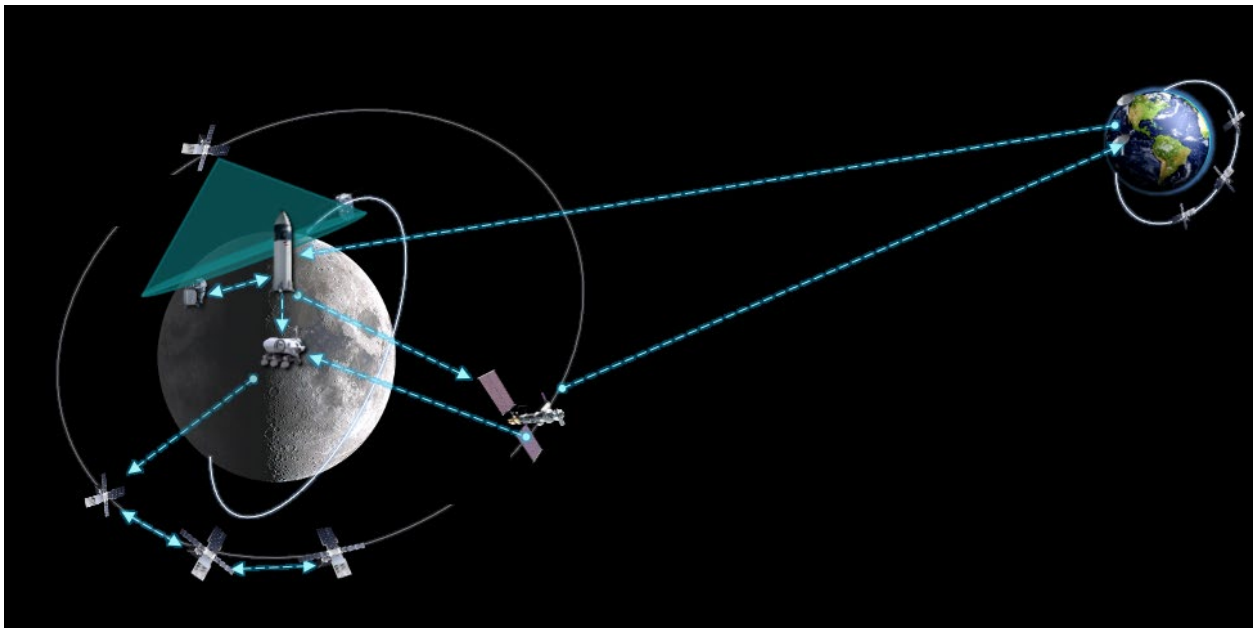

Figure 1: LunaNet Service Providers will provision services from Earth-based, Lunar-orbiting and Lunar Surface Systems

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 and institutions 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.

The initial instantiation of LunaNet, referred to as LunaNet 1.0, will include LNSPs from National Aeronautics and Space Administration (NASA), European Space Agency (ESA), and Japan and include Earth Ground-based and Lunar Orbiting systems. These LNSPs will be comprised of government systems or commercial service providers under contract to an agency. Other provider systems (commercial or international agency) may be compliant with the LunaNet 1.0 specifications. This first instantiation will meet the needs of early missions and be evolvable to meet the growing needs of a long-term lunar presence. All network services for all users are not required to be met by a single LNSP. The expectation is that the needs of users will be met through a combination of interoperable LNSPs. Interoperability across this network-of-networks can be achieved through negotiation of mutually-agreed-upon standards and interfaces that are reflected in this document.

This document is structured as follows. Chapter 1 provides general context regarding the purpose and scope of this document (and LunaNet). Chapter 2 provides an overview of the various segments and

interfaces defined in LunaNet. Chapter 3 gives an overview of the LunaNet user services with dedicated sections on communication (Section 3.1), position, navigation, and timing (Section 3.2) and messaging (Section 3.3) services. Chapter 4 provides the specifics for the interfaces between LNSP and User. Chapter 5 provides an overview of the services provided between LNSPs. Chapter 6 provides the specifics for the interfaces between LNSPs. Chapter 7 contains the references and appendices where Appendix B provides the signal interface descriptions and Appendix C provides a link between the signal interfaces and proposed navigation services. Finally, several applicable documents are defined, for which [AD1 Vol-A] is included in this version and describes the Augmented Forward Signal (AFS).

1.1 PURPOSE

The purpose of this specification is to define the standards and interfaces for LunaNet LNSPs to administer interoperable services to meet the identified needs of missions operating in the lunar vicinity. This document and the accompanying Applicable Documents (ADs) are part of a top-level set of LunaNet 1.0 documents that will provide for traceability of all individual LunaNet 1.0 LNSP projects to a common architecture description, concept of operations, and standards (See Figure 2). This will allow users to design their systems with the expectation of interoperability with multiple LunaNet 1.0 providers. This document has been developed to be compatible with the International Communication System Interoperability Standards (ICSIS) and to be aligned and informed by the work of the Interagency Operations Advisory Group (IOAG). Any individual provider is not required to offer all services and interfaces in this document. The goal is that the aggregation of providers will have the interfaces and services described in LunaNet 1.0. External to this specification, the LunaNet 1.0 partners will coordinate the plans for their systems to ensure that the coverage and services described in the Architecture Description and Concept of Operations documents will be available from the combination of the partner systems. This will be part of the governance process as identified below. It is also possible for providers to offer services and interfaces beyond what is described in this document. However, those services and interfaces may not be interoperable between service providers, thereby limiting the service options for a user on or around the Moon.

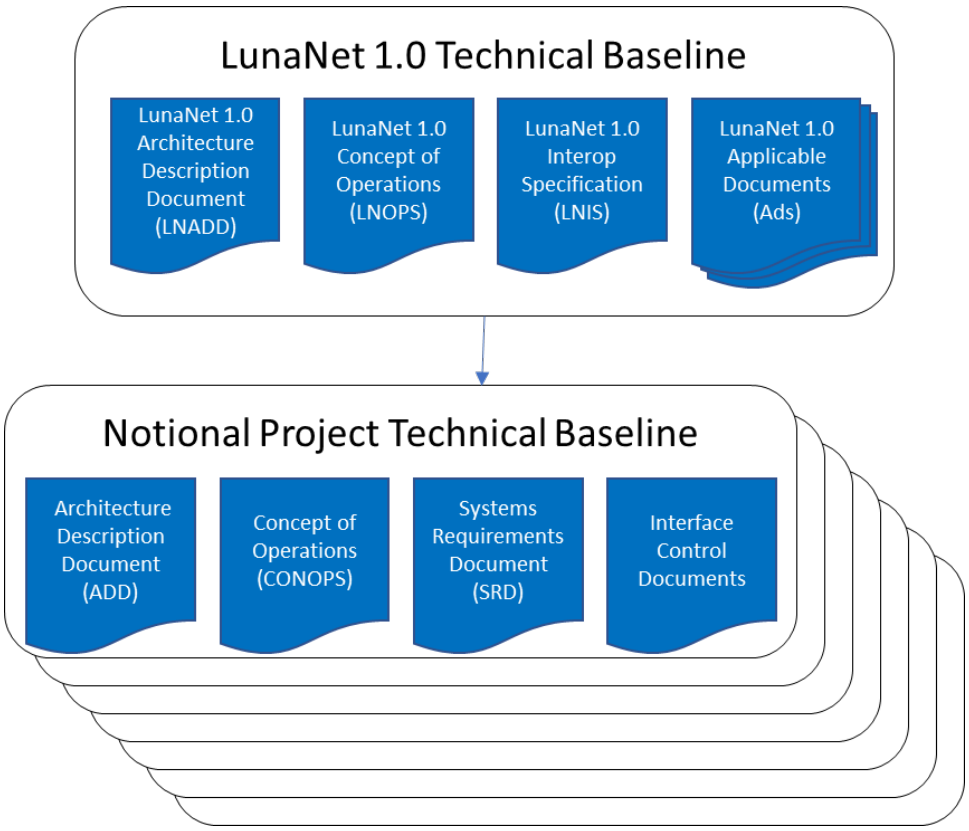

Figure 2: LunaNet 1.0 Technical Baseline Documentation

This current version of the document was written and approved by the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA). As identified in Appendix D Section Mapping Between LNIS v5 and v5, this version has removed sections included in previous versions of this document, in order to focus on only those items that are applicable to the LunaNet 1.0 instantiation. These are the services planned for the early lunar missions. Any items identified with a TBR, TBD, or TBC are intended to be resolved to be incorporated into LunaNet 1.0, unless otherwise noted. This document will be updated as LunaNet evolves.

The services and interfaces addressed in this document will be deployed by LNSPs over time. Development and procurement activities conducted for LunaNet 1.0 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. LunaNet 1.0 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. Expansion beyond LunaNet 1.0 will include additional services and interfaces added to an evolution of this document. 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 and 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 LunaNet standards and specifications to enable interoperable communication and PNT services for users operating on the lunar surface and in cislunar space for the LunaNet 1.0 instantiation of LunaNet. This release of the document contains future work per the TBD/TBR section, that will be resolved in future releases of the document to fully specify LunaNet 1.0.

Governance for sustained LunaNet is under study in international fora and may not be established prior to initial operational LunaNet 1.0 lunar relay services. Governance consists of developing and applying shared principles, norms, rules, and decision-making procedures that shape the evolution and use of LunaNet in the context of the relevant international legal framework. Governance can be divided into the legal and regulatory regime and technical governance.

There is a recognized need for near-term technical governance through coordination and administration by the partners engaged in providing LunaNet services on topics that are outside the scope of the interoperability specification. Areas requiring early coordination will be agreed upon through coordination among LunaNet administrative partners, the charter of which is outside the scope of the LNIS.

1.3 SECURITY

This section outlines the fundamental security principles and practices to be adhered to by all users and providers of LunaNet resources. The intent is to ensure the confidentiality, integrity, and availability of data and services within LunaNet.

- Confidentiality – The data and services are only accessible to authorized users and providers.
- Integrity – The data and services are accurate and protected from corruption.
- Availability – The data and services are accessible when needed.

Users and providers are expected to ensure security risk management, data and services protection, incident response, and compliance with related regulations throughout the systems and data lifecycle.

Users and providers are expected to adhere to security standards as outlined in this document or as dictated under appropriate regulations and are expected to employ continuous improvement as LunaNet evolves.

Users and providers are expected to update periodic cybersecurity training, awareness programs, and related programs to ensure the safe and proper use of LunaNet resources.

Regulations for users and providers are subject to applicable international, national, agency, program, corporate, or other affiliations.

This section is considered informational. LunaNet Interoperability Security Specifications [AD8] will be the repository for detailed security specifications. Once approved, [AD8] will be the authoritative source for interoperable LunaNet security requirements.

1.4 APPLICABLE DOCUMENTS

[AD1] LunaNet Signal-in-Space Recommended Standard –
[AD1 Vol-A] Augmented Forward Signal (Volume A)
[AD1 Vol-B] Point-to-Point Signals (Volume B) {LNIS-TBD-AD0001VB}

[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 LunaNet Reference Time System Standard {LNIS-TBD-AD0005}
[AD6] LunaNet Data Services Document {LNIS-TBD-AD0006 }
[AD7] LunaNet LunaSAR Definition Document { LNIS-TBD-AD0007}
[AD8] LunaNet Interoperability Security Specifications {LNIS-TBD-AD0008 }

Other applicable documents:

The following documents are applicable to the extent noted within this LunaNet Interoperability Specification.

[AD9] CCSDS 131.0-B-5, TM Synchronization and Channel Coding
[AD10] CCSDS 133.1-B-3, Encapsulation Packet Protocol
[AD11] CCSDS 231.0-B-4, TC Synchronization and Channel Coding
[AD12] CCSDS 401.0-B-32 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft
[AD13] CCSDS 414.1-B-3 Pseudo-Noise (PN) Ranging Systems
[AD14] CCSDS 415.1-B-1 Data Transmission and PN Ranging for 2 GHz CDMA Link Via Data Relay Satellite
[AD15] CCSDS 702.1-B-1, IP Over CCSDS Space Links
[AD16] CCSDS 732.0-B-4, AOS Space Data Link Protocol
[AD17] CCSDS 732.1-B-3, Unified Space Data Link Protocol
[AD18] CCSDS 734.1-B-1, Licklider Transmission Protocol (LTP) for CCSDS
[AD19] CCSDS 734.2-P-1.1[1], CCSDS Bundle Protocol Specification
[AD20] CCSDS 911.1-B-5, Space Link Extension-Return All Frames Service Specification
[AD21] CCSDS 911.2-B-4, Space Link Extension-Return Channel Frames Service Specification
[AD22] CCSDS 912.1-B-4, Space Link Extension-Forward CLTU Service Specification
[AD23] CCSDS 913.1-B-2, Space Link Extension – Internet Protocol for Transfer Services
[AD24] CCSDS 922.3-B-1, Cross Support Transfer Service – Forward Frame Service
[AD25] RFC 9172, Bundle Protocol Security (BPSec)
[AD26] RFC 9174, Delay-Tolerant Networking TCP Convergence-Layer Protocol Version 4
[AD27] IOAG Service Catalog #1, 3.0

[1] To be replaced by Blue Book when published

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 3, LunaNet has a Lunar Segment and an Earth Segment. The Lunar Segment contains elements that could either be in lunar orbit or, in the future, on the lunar surface, though they may be referred to in general as "lunar relays." An LNSP may elect to provide a selection of services from the variety of services defined in this specification (e.g., PNT services).

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 4, is an intra-network example where a single provider (e.g., LNSP A or B) may use an LNIS standardized interface with many Users (e.g., User X and Y) and an inter-network example where multiple providers (e.g., LNSP A and B) interface directly to exchange user data (note: other interfaces between an LNSP Lunar Relay-Earth may be employed). The LNSP Lunar Segment-User Interface and LNSP Earth Segment-User -Direct-with-Earth Interface are standardized. The interface between the LunaNet Earth Segment and the User Earth Segment may 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.

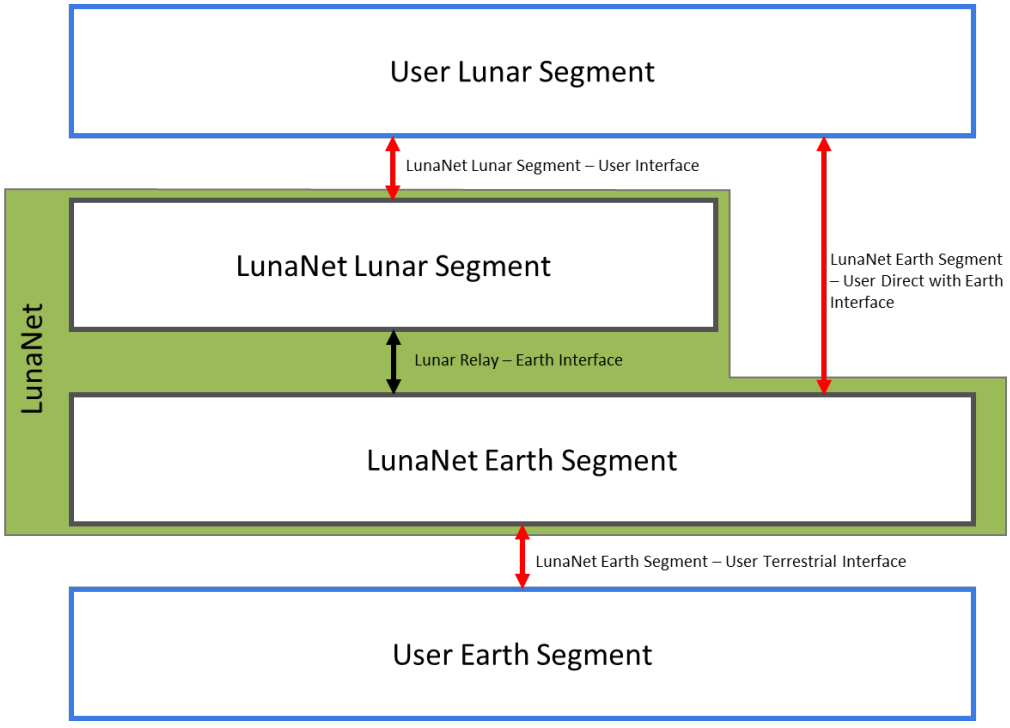

Figure 3: LunaNet Segments

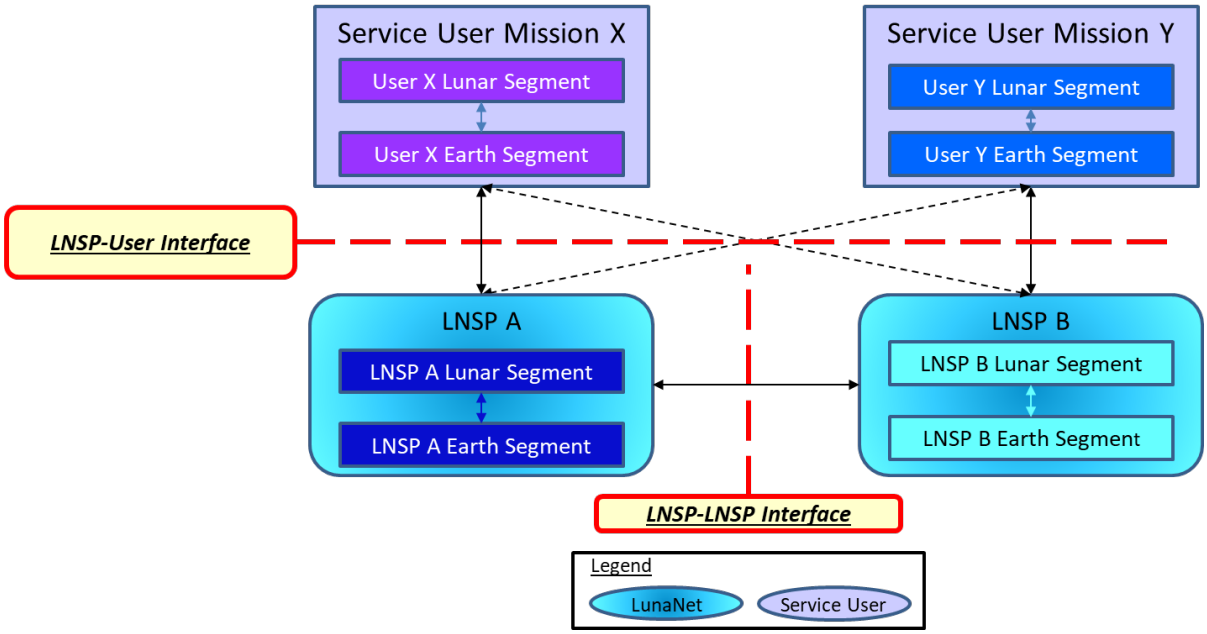

Figure 4: LunaNet Standard Services and Interfaces Between LNSPs and Users

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 4.

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 (as illustrated by the dashed lines in Figure 4), 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.

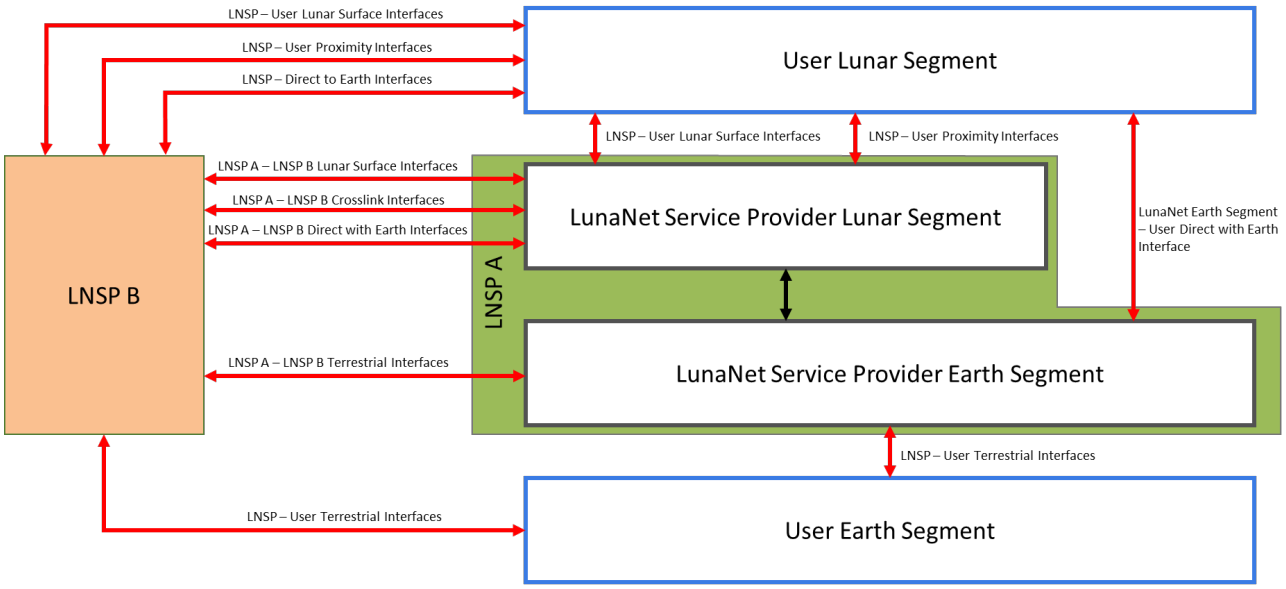

Figure 5: LunaNet Service Providers Interfaces

The LNSP interfaces are depicted in Figure 5. 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 5. Note that some of the interfaces identified in this illustration are not included in this LNIS document for LunaNet 1.0 and are identified to be potentially standardized in the future.

Table 1: Lunar Network Service Provider Interfaces

Interface Name	Interface Description	Document Section
LNSP-User Proximity RF Interfaces	User interfaces with lunar orbiting provider nodes	4.1
LNSP-User DWE RF Interfaces	Interfaces between user lunar systems and provider Earth systems	4.2
LNSP-User Contingency RF Interfaces	Very low data rate proximity and DWE interfaces for contingency operations	4.3
LNSP-User Terrestrial Interfaces	Terrestrial interfaces between user and provider	4.4
LNSP A-LNSP B Crosslink Interfaces	Interfaces between two LNSPs lunar orbiting nodes	6.1
LNSP A-LNSP B DWE Interfaces	Interfaces between an LNSP lunar system and a different LNSP earth system	6.2
LNSP A-LNSP B Terrestrial Interfaces	Terrestrial interfaces between two LNSPs	6.3

All LNSPs providing communication and PNT services shall adhere to the Lunar Reference System and Lunar Time System Standard [AD5].

2.1 LUNANET REFERENCE TIME

Note: this section is included in this document until [AD5] is available.

To ensure LNSP systems are interoperable (in particular concerning the delivery of PNT services), service products (i.e., AFS time of transmission message MSG-G8 as defined in Table 5) need to be referred to LunaNet Reference Time (LRT). If there is an offset between LNSP System Time (LST) and LRT, the LNSP shall implement a mechanism to estimate this offset and disseminate (e.g., through AFS) it to the user.

As shown in Figure 6, there are several ways for a LNSP to define a relationship between LRT and LST, for instance free-running or continuously steered in frequency. The examples provided in this figure simply illustrate that there are different ways to implement LST, but does by no means aim to provide an extensive overview. In the figure, LNSP-1 System Time is free-running, LNSP-2 and LNSP-4 implement periodic time corrections, while LNSP-3 is continuously steering its System Time. The LST – LRT offset is only shown for LNSP-1 system time, but it is also defined for the other LNSP system times (e.g., LNSP-2 System Time to LRT). Furthermore, a LNSP may also provide different offsets (e.g., LST – UTC).

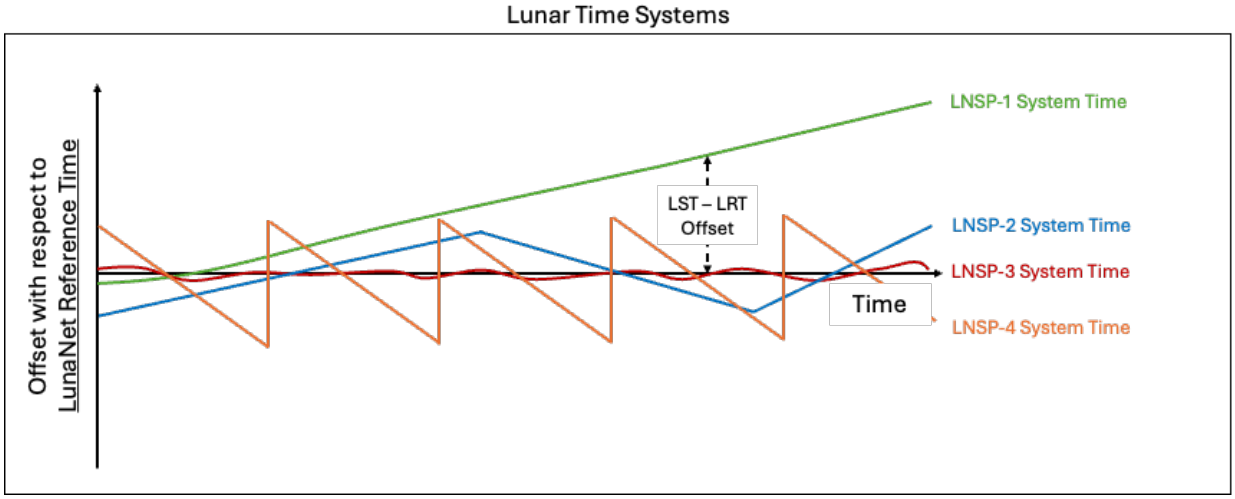

Figure 6: Examples of relationships between LNSP System Time (LST) and LunaNet Reference Time (LRT). This figure aims to show several options but does not aim to provide an exhaustive overview.

3 USER SERVICES

This section describes the communications, PNT, and data services to be provided by LNSPs. It is anticipated that users will be able to make productive service combinations to enhance and augment their communications and navigation capabilities. This will be described further in the LunaNet 1.0 Concept of Operations document. 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.

3.1 COMMUNICATIONS SERVICES

This section begins the description of the communications services to realize LunaNet version 1.0. The details of network protocols and interfaces are contained later in the document, with the appropriate sections identified in Table 2.

Table 2: Communication Service & Interface LNIS Section Numbers

	LNSP to User			LNSP to LNSP		
	Proximity	DWE	Terrestrial	Proximity	DWE	Terrestrial
Communication Service Description	3.1 (this section)			5.1		
Link Layer Interface	4.1 (Nominal) 4.3 (Contingency)	4.2	4.4	6.1(Crosslink)	6.2	6.3
Network Layer Interface	4.5			6.4		

There are two communications service types: real-time, assuming contemporaneous end-to-end connectivity, and store-and-forward, which explicitly deals with long delays, disruption, and/or disconnection. See Figure 7. Note that the service between 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, and real-time processing in transmit and receive modem and switching systems 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.

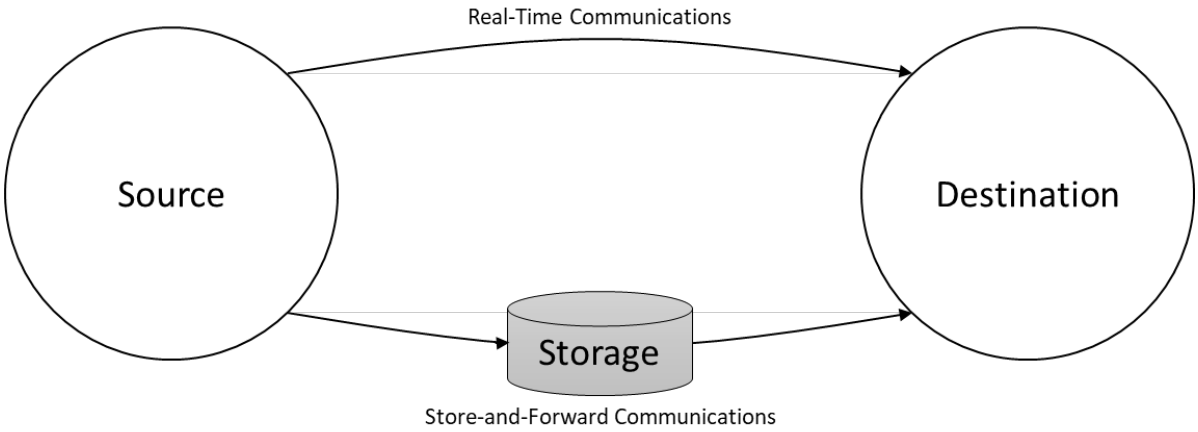

Figure 7: Two Types of Communications Services

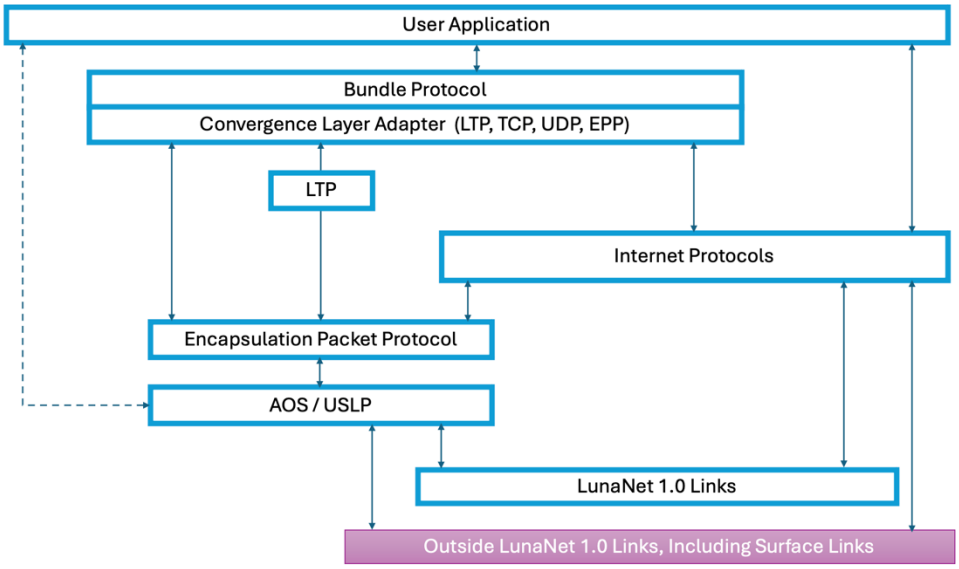

Figure 8: User Application Simplified Protocol Stack

Figure 8 is a simplified view of the protocol stack options for LunaNet user applications. Important details not provided include some specifics of DTN Convergence Layer options, transport protocols, encapsulations, security protocol options, and others. 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) [AD16] and Unified Space Data Link Protocol (USLP) [AD17] standards. The direct use of link layer services is intended for messaging services for LunaNet protocols only (as described in [AD6]) and should be discouraged for user applications (which is why the line is dotted rather than solid in Figure 8, between the user applications and AOS/USLP). Note that user applications over AOS/USLP can contain and process their own protocols (such as Space Packet Protocol), but that is their responsibility, not part of LunaNet 1.0 or the LNSP role. Connections to a LunaNet access point over any available link will allow the user's data to route to its destination (as described in [AD6]). Though LunaNet permits link layer services, network-based applications will allow for the evolution and scalability of both user and provider systems. The box in Figure 8 for "Outside LunaNet 1.0 Links" represents LunaNet network layer interoperability over connectivity not specified in LNIS version 5 (e.g. over surface-to-surface links, among other examples), as discussed in Section 4.5.

The remainder of this subsection provides an overview of the LunaNet data services and their key aspects. For full interoperability, additional details are contained in [AD6] regarding the necessary implementation aspects for LunaNet data link framing, encapsulation, IP packet handling, DTN bundle agent operation, and convergence layer adapter protocol support.

3.1.1 REAL-TIME COMMUNICATIONS SERVICES

Real-time communications services may be provided at both the link layer and the network layer. These real-time services will require availability of the full end-to-end path.

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 in some special cases due to user link layer security methods selected by the users or to enable higher speed operations (e.g. due to potential full-hardware implementations). The link layer service may include the multiplexing, de-multiplexing, and forwarding of user data frames (as described in [AD6]). These services will transport data link frames consistently so that other services provided by the framing layer (e.g., Variable Coding and Modulation (VCM) services, bitstream services, etc. as defined for AOS) are maintained and key relative quality of service aspects can be understood (as described in LNIS-TBD-AD0006).

For interoperability, the link layer services will initially require CCSDS AOS frames [AD16], or fixed-length USLP 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) [AD17] 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 orbital or communications geometries or other unplanned events (store-and-forward networking services should be used instead when these conditions are not tenable). Aspects required for interoperability such as the frame sizes, transport, encapsulation, and delivery of different types of frames are fully discussed in LNIS-TBD-AD0006.

The LunaNet Real-Time link layer communication services are aligned with the relevant forward and return services defined in the IOAG Services Catalog #1 [AD27][2].

[2] A link layer GVCID routing function is anticipated when these services are delivered via an orbiting lunar relay, further details will be defined in [AD6].

3.1.1.2 REAL-TIME IP NETWORK LAYER COMMUNICATIONS SERVICES

Real-time IP 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. 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 but not limited to 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 3 below provides a summary of the IP service interfaces. The [AD6] document defines the details of the IP networking stack, including protocol versions and other stack details {LNIS-TBD-AD0006}.

Table 3: IP Service Interfaces

Interface Name	Description	Applicable Interfaces	Applicable Documents	LunaNet 1.0
IP over CCSDS Encap/AOS	IP packets in CCSDS Encapsulation Packets over AOS frames	All AOS link layer service interfaces	[AD15] CCSDS 702.1-B-1 [AD10] CCSDS 133.1-B-3 [AD16] CCSDS 732.0-B-4	Yes
IP over CCSDS Encap/USLP	IP packets in CCSDS Encapsulation Packets over USLP frames	All USLP link layer service interfaces	[AD15] CCSDS 702.1-B-1 [AD10] CCSDS 133.1-B-3 [AD17] CCSDS 732.1-B-3	Yes
IP over Wi-Fi™	IP packet transmission over wireless Ethernet	Lunar surface wireless	IETF and IEEE standards [AD6]	No
IP over 3GPP	IP packet transmission over 3GPP links	Lunar surface wireless	IETF and 3GPP standards [AD6]	No

3.1.2 DTN NETWORK COMMUNICATIONS SERVICES

Network layer services over links which are characterized by disruption/delay or where a robust end-to-end path is not available (or at full bandwidth) will be supported by DTN. The Bundle Protocol version 7 (BPv7) shall be used. Over proximity and DWE space links, the convergence layer adapter carries bundles within CCSDS Encapsulation Packets over AOS or USLP. 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 213.1.1.2). For long haul or periodically disrupted links, the DTN data bundles are carried by either a Licklider Transmission Protocol (LTP) convergence layer with LTP segments [AD18] or directly in encapsulation packets, which will be carried over an AOS or USLP link layer (see section

3.1.1.1). The LTP option would insert LTP segments in encapsulation packets that are carried over the link layer. Table 4

below provides a summary of these options, with other detailed specifications listed in LNIS-TBD-AD0006.

The CCSDS standards for Bundle Protocol Version 7 [AD19] and BPSEC are currently being finalized based on IETF RFC 9171 and RFC 9172. Bundle protocol extensions for QoS and Custody Transfer are currently being defined with CCSDS Orange Books expected to be published in 2025. Routing is expected to initially be performed based on pre-scheduled links with required information being exchanged based on current practices and should be covered in corresponding ICDs.

Table 4: Bundle Protocol Service Interfaces

Interface Name	Description	Applicable Documents
Bundle Protocol	Bundle Protocol for Store-and-Forward Services	[AD19] CCSDS 734.2-P-1.1[3]
Bundles / TCPCL	Bundles are forwarded via TCP convergence layer adapter over TCP/IP	[AD19] CCSDS 734.2-P-1.1[3]
Bundles / UDPCL	Bundles are forwarded via UDP convergence layer adapter over UDP/IP	[AD19] CCSDS 734.2-P-1.1[3]
Bundles / LTPCL	Bundles are forwarded via LTP convergence layer adapter over Encapsulation Packet Protocol	[AD19] CCSDS 734.2-P-1.1[3] [AD10] CCSDS 133.1-B-3
Bundles / EPPCL	Bundles are forwarded via EPP convergence layer adapter.	[AD19] CCSDS 734.2-P-1.1[3] [AD10] CCSDS 133.1-B-3

3.1.3 COMMUNICATIONS SERVICES ADDRESS AND ID REGISTRATION

Entities will need to register addresses and IDs utilized by the protocols that make up the LNIS protocol stack in order to inter-operate as part of LunaNet. Where applicable, values may be registered in accordance with existing processes using Space Assigned Numbers Authority (SANA) and Internet Assigned Numbers Authority (IANA) registries.

LNIS-TBD-AD0006 will be developed in future LNIS versions to provide details of the addresses and IDs that need to be registered for LunaNet, and references for the process by which registration of each particular address and ID is performed.

[3] CCSDS profile of RFC 9171 - Bundle Protocol Version 7. Currently [AD19] CCSDS Draft Recommended Standard 734.2-P-1.1 at time of writing, to be published as CCSDS 734.2-B-2.

3.2 POSITION, NAVIGATION, AND TIMING SERVICES

PNT services enable missions to determine their 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 measuring Doppler, ranging, and 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.

The PNT services can be grouped into three broad categories, as shown in Figure 9:

1. Broadcast services, referred to in this specification as the Lunar Augmented Navigation Service (LANS), consisting of signals transmitted continuously by multiple LNSP nodes to any number of users within a defined service volume as described in Section 3.2.1. PNT services provided by LANS are comparable to terrestrial Global Navigation Satellite Systems (GNSS), in the lunar environment, wherein four or more signals observed simultaneously by a user can be processed to form a complete position, velocity, and time (PVT) solution. The specifications for the GNSS-like Augmented Forward Signal (AFS) are provided in [AD1 Vol-A].
2. Direct link services are provided through Point-to-Point links (P2P). These services are provided via direct links between the user and a provider node (i.e., LNSP). Interface definitions for those links are provided in Appendix B, with detailed specifications in [AD1 Vol-B]. Alternatively, a signal that is not inherently designed to offer PNT observables may still be employed to transmit messages that support PNT.
3. Supplemental Navigation Services, as described in Section 3.2.3 provide PNT products via messages.

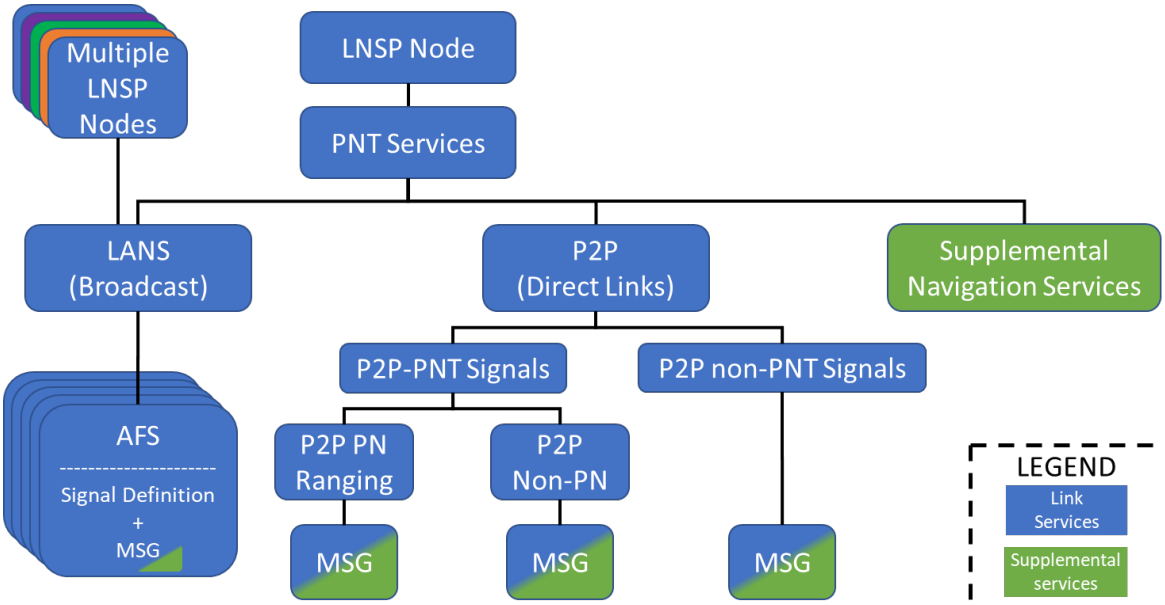

Figure 9: PNT Services Provided by LNSP

Note: In Figure 9 *the blue color represents PNT link services (i.e. LANS and P2P), the green color represents services fulfilled via delivery of messages. The multiple colors for the "Multiple LNSP Nodes" boxes show LANS being provisioned by different LNSPs.*

PNT link services (LANS and P2P) described above (and further detailed in Sections 3.2.1 and 3.2.2) require the LNSP to have knowledge of the current position, velocity, and timing (PVT) of its own relay satellites, as well as future predicted values. This information shall be forwarded to users for the exploitation of the related services, in the form of messages MSG-G4 (clock and ephemeris data) and MSG-G5 (almanac). Section 3.3 identifies additional messages that can be used to inform a comprehensive state of LNSP node(s).

For interoperability in the PNT domain, additional specifications are being developed to include the following for LunaNet 1.0:

1. LunaNet Signal-in-Space Recommended Standard [AD1]
    a. Augmented Forward Signal (LSIS) – Volume A [AD1 Vol-A]
    b. Point-to-Point Signals – Volume B [AD1 Vol-B] – {LNIS-TBD-AD0001VB }
2. LunaNet Measurement Schema and Parameters Document [AD2]– { LNIS-TBD-AD0002}
3. LunaNet Detailed Message Definition Document [AD3]– {LNIS-TBD-AD0003}
4. Lunar Reference System and LunaNet Reference Time System Standard [AD5]– {LNIS-TBD-AD0005}
5. LunaNet Data Services Document [AD6]– {LNIS-TBD-AD0006}
6. LunaNet Interoperability Security Specifications [AD8] – { LNIS-TBD-AD0008}

[AD1 Vol-A] and [AD1 Vol-B] define signal structures for LNSP and users to allow effective interoperability in the PNT domain for LANS and P2P respectively. [AD1 Vol-B] is a placeholder for defining the interoperable aspects to be developed in concert with the LNSPs, if needed. [AD2] will provide the necessary measurement implementation schemas, and [AD3] will provide the detailed definition of messages. Lunar reference and time systems are defined in [AD5] to ensure interoperability and consistency for the LunaNet PNT services. Finally, [AD8] will provide authentication and security definitions for PNT services.

The messages specific to PNT are identified in [AD1 Vol-A], [AD1 Vol-B], and [AD3]. When LANS and direct link (P2P) service messages share the same specification, their definition is provided in [AD3]. Otherwise, when a message is implemented differently amongst service types, the detailed specification is provided in [AD1 Vol-A] for LANS or [AD1 Vol-B] as needed for P2P links.

3.2.1 BROADCAST SERVICE

A broadcast service is expected to be provided with relatively wide field-of-view antennas to cover as much of the service volume as practical with the same signal. Continuous transmission allows for low latency information dissemination independent of dedicated communication links. For LunaNet 1.0, the Augmented Forward Signal (AFS) is the only defined signal for broadcast service, as described in Section 3.2.1.1.

3.2.1.1 LUNAR AUGMENTED NAVIGATION SERVICE (LANS)

The signal designated for providing the LANS establishes a broadcast PNT functionality. This Augmented Forward Signal (AFS) broadcast enables multiple-user reception of the signal simultaneously (one-to-many concept). The service will be composed of a collection of AFS-transmitting LNSP nodes, that are time synchronized (see Section 3.2.1.1) against a common reference time called LunaNet Reference Time or LRT [AD5] aimed at achieving global lunar coverage of a minimum of four simultaneous LANS nodes in view at any given time (note: This is beyond LunaNet 1.0.). In order to establish the LANS, the AFS uses a Code Division Multiple Access (CDMA) signal structure at a single center frequency in the 2483.5 – 2500 MHz band (S-band). Users requiring PNT can employ omnidirectional or hemispherical antennas to receive AFS from multiple

LunaNet nodes simultaneously (many-to-one concept) (either from one LNSP or different LNSPs), as illustrated in Figure 10. A sufficient number of LNSP nodes in view in a service volume at any given time, enables users in that service volume to compute their PVT. In this way LANS overcomes the challenges of PNT services based on communication links that require dedicated links that must be scheduled. Furthermore, the AFS offers a low-rate forward broadcast communication channel that, beyond the necessary dissemination of clock, ephemeris, and almanac data for PNT, can be used to provide supplemental messages (e.g., P2P links scheduling messages, alert messages, etc.). For LunaNet 1.0, LANS is expected to provide a regionalized service to the lunar South Pole volume.

Note: The PFS5 ID, used in previous versions to indicate the AFS, has been retired in this version. The Augmented Forward Signal is now simply referred to as AFS.

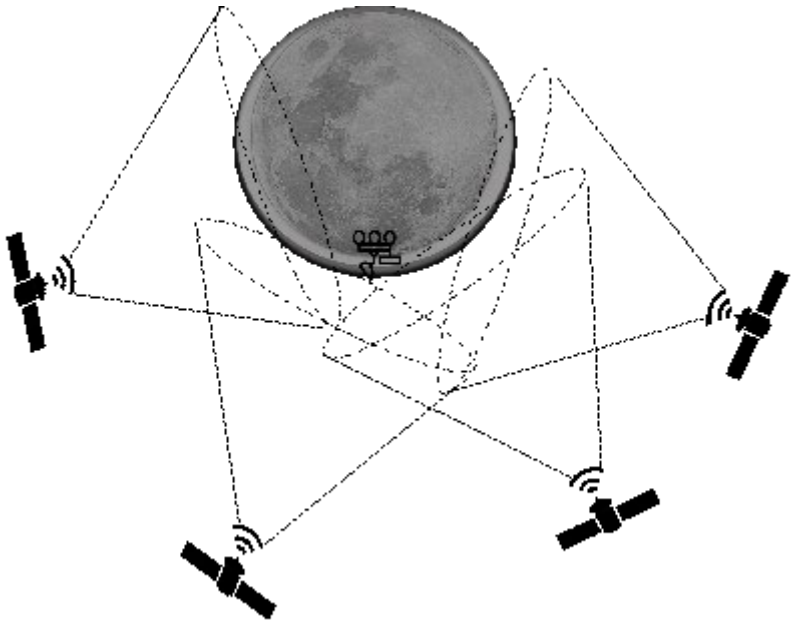

Figure 10: LANS PNT Concept Provided by LunaNet Service Provider Nodes

AFS users compute the time-of-flight of the signal and received frequency of the signal using information extracted from the broadcast navigation messages (i.e., time and frequency information) to form pseudorange, Doppler shift, and carrier phase measurements. Using a collection of observables from different LNSP nodes and the accompanying broadcast navigation messages (i.e., satellite ephemerides that are modulated on the AFS-I data channel), users can autonomously compute their position/velocity and the difference between the local receiver clock and the LNSP system reference clock (that is synchronized to LRT). [AD1 Vol-A] provides the specification of the AFS and associated messages modulated onto the AFS data channel; these include the transmission periodicity, cadence, and latency as well as the prioritization of messages.

As with all other PNT services, a common lunar-centric reference frame and time system is defined (further detailed in [AD5]). Each LNSP shall ensure they either implement these reference systems directly (e.g., signals are synchronized with the LRT 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 system time to the LRT as shown in Section 2.1 and/or provide the transformation and/or rotation between the reference frame adopted by the LNSP and the reference system specified within [AD5]).

In order for users to compute accurate measurements for PVT estimation, each LNSP shall ensure the AFS is provided with signal-in-space error (SISE) within the maximum values specified in [AD1 Vol-A]. Furthermore, each LNSP shall provide predicted SISE performance as part of MSG-G4. This allows users to derive reliable navigation solutions at a dependable level when receiving AFS from multiple LNSP nodes that may have SISE that varies within the tolerances defined in [AD1 Vol-A].

The full LANS service volume, depicted in Figure 11, identifies the minimum global lunar service volume in which LANS services will be provided and performance specifications must be met. 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.

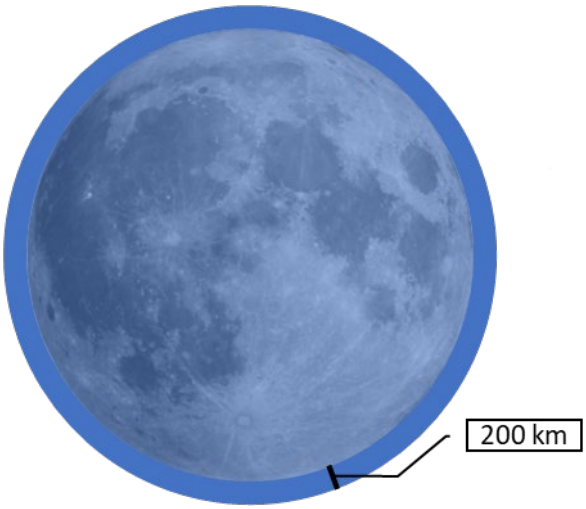

Figure 11: LANS Full-Service Coverage and Performance Volume

However, an evolutionary approach is anticipated to build toward the full-service volume, with an expected start over the South Pole region of the Moon. This is notionally shown in Figure 12. While Section 1 identifies the lunar far side as an area of interest for LunaNet 1.0, initial LNSP contributing to LANS are expected to focus their services on the South Pole region. Nevertheless, individual LNSP nodes may still provide the AFS broadcast signal on the lunar far side.

Figure 12: Notional LANS South Pole Service Coverage and Performance Volume

3.2.2 DIRECT LINK SERVICES

Direct link PNT services are provided with the use of dedicated communication interfaces between an LNSP and a user. The group of P2P PNT services can be categorized by service type offered:

1. LNSP One-Way Doppler Reference, described in Section 3.2.2.1
2. LNSP Two-Way Doppler Measurements, described in Section 3.2.2.2
3. LNSP Two-Way Range Measurements, described in Section 3.2.2.3
4. LNSP One-Way Doppler Measurements, described in Section 3.2.2.4

Link interface definitions for these services are provided in Appendix B, with detailed specifications for these interfaces provided in [AD1 Vol-B]. A relationship of PNT services offered with each proximity link interface is provided in Table C-1 and Table C-2.

Note 1: Signals that are not inherently designed to offer PNT observables may still be employed to transmit messages that support PNT (e.g., satellite ephemerides, observables, etc.).

Note 2: A user navigation system may complement LNSP observations with other measurement types, however those are not addressed in this document, as they are not LunaNet services.

3.2.2.1 LNSP ONE-WAY DOPPLER REFERENCE

When an LNSP transmits a signal towards the user, the user can generate PNT observables derived from the reception and measurement of signal characteristics. This section describes one-way Doppler reference signal services provided by an LNSP node as illustrated in Figure 13. Users are presented with a direct link signal transmitted from a LNSP node, from which they can derive Doppler observables to inform their PVT estimates.

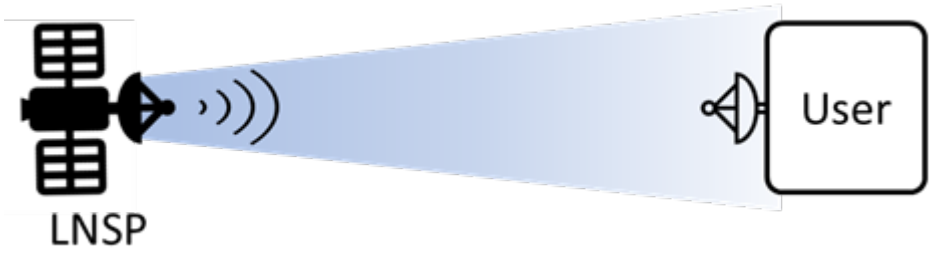

Figure 13: LNSP One-Way Doppler Reference Signal

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 LNSP node. This is best accomplished with the use of a fixed frequency transmission by the LNSP.

Differences in the measured frequencies by the user will be due to Doppler, as well as frequency offsets from both the LNSP node's and user's frequency oscillator sources. The LNSP node providing this service shall convey its reference frequency value and deviations via message (MSG-G9), as identified in Section 3.3.

Note: specific signal specifications supporting this service are provided in [AD1 Vol-B] {LNIS-TBD-AD0001VB}.

3.2.2.2 LNSP TWO-WAY DOPPLER MEASUREMENTS

Two-way links are established when the signal transmitted by the provider is received by and then re-transmitted by the user. Two-way Doppler measurements performed by LNSP are two-way radiometric services where the LNSP node compares the transmitted and received signals to derive observations of round-trip Doppler by measuring the differences in phase between the transmitted and received signal center frequencies at predetermined time intervals. When that retransmission is coherently related to the received signal through a defined turnaround ratio, as illustrated in Figure 13, it removes systematic errors such as the user satellite clock. In this service, the measurements are generated at the provider-level and are disseminated to the required user element via message MSG-G13 indicated in Section 3.3.

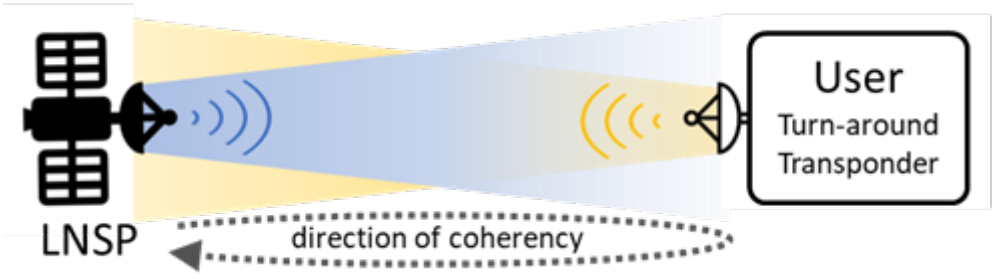

Figure 14: Two-Way Measurements Performed by LNSP Node

Note: specific signal specifications supporting this service are provided in [AD1 Vol-B].

3.2.2.3 LNSP TWO-WAY RANGE MEASUREMENTS

LNSP range measurements are based on coherent two-way links as defined in Section 3.2.2.2 and depicted in Figure 12. Two-way range measurements performed by the LNSP are two-way radiometric services where the LNSP node compares a specific time mark of the transmitted and received signals to derive observations of round-trip range in terms of time-of-flight delay. This concept is equivalent to classical two-way radiometric tracking, in which the originator of the ranging signal is the LNSP satellite instead of an Earth tracking station.

The range measurements performed by the LNSP can be separated into two categories:

1. Non-regenerative ranging, or transparent ranging, which 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 [AD13] CCSDS 414.1-B-3 may be used for this purpose.

2. Regenerative ranging, which 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 [AD14] CCSDS 415.1-B-1 and [AD13] CCSDS 414.1-B-3 may be used for this purpose.

In this service, the measurements are generated at the provider-level and are disseminated to the required user element via message MSG-G13 identified in 3.3.

Note: specific signal specifications and use of the standards mentioned above are provided in [AD1 Vol-B].

3.2.2.4 LNSP ONE-WAY DOPPLER MEASUREMENTS

One-way Doppler measurements performed by LNSP nodes consist of carrier phase measurements on incoming user signals, as depicted in Figure 15. Users provide signals that enable LNSP nodes to compute one-way Doppler observables. The resulting one-way measurement observables generated at the provider-level are disseminated to the user element performing the PVT estimates via message MSG-G13 identified in Section 3.3.

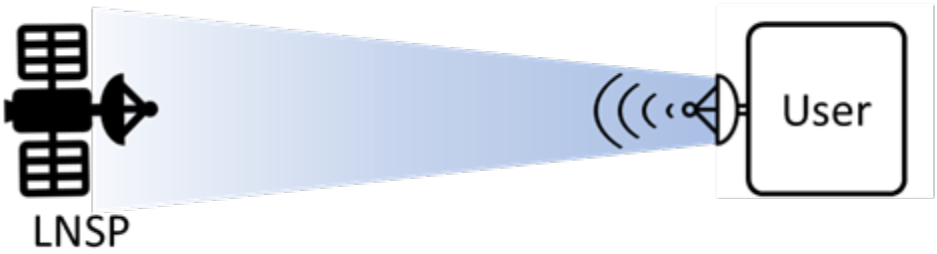

Figure 15: One-Way Measurements Performed by an LNSP Node

One-way Doppler measurements may be carried out for most incoming radio communications signals by tracking the frequency and phase of the received signal and reporting the delta with respect to a defined source frequency reference. 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 LNSP's and the user's frequency sources, 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.

Note: specific signal specifications supporting this service are provided in [AD1 Vol-B], if needed.

3.2.3 SUPPLEMENTAL NAVIGATION SERVICES

Supplemental navigation services consist of navigation products, delivered via messages to the users. Navigation products are defined to support and complement the PNT services. This section provides an overview of the supplemental navigation products. Messages linked to such products are described in Section 3.3.

3.2.3.1 LUNAR REFERENCE FRAME RELATED MESSAGES

Each LNSP node shall provide their ephemeris information in either the common specified lunar reference frame (i.e., defined in [AD5] – {LNIS-TBD-AD0005}) or provide a means for the necessary coordinate transformations with respect to the specified lunar reference frame. Message MSG-G32 offers a means to provide transformations between different reference frames.

3.2.3.2 LUNANET REFERENCE TIME

Each LNSP shall provide PNT services either directly synchronized with the LunaNet Reference Time (LRT) (i.e., defined in [AD5] – {LNIS-TBD-AD0005}) or provide the relevant time offsets allowing a user to synchronize its local clock to LRT. Furthermore, time offsets with respect to other relevant timescales (e.g., UTC) can be provided to lunar users (e.g. using MSG-G30).

3.2.3.3 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 and Time System Standard {LNIS-TBD-AD0005} and the coefficients can be distributed by LNSP provider nodes. An LNSP may disseminate the lunar potential models in MSG-G17 (ancillary information).

3.2.3.4 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 and Time System Standard {LNIS-TBD-AD0005} and may be distributed by LNSP provider nodes in MSG-G17 (ancillary information).

3.2.3.5 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. An LNSP shall disseminate the almanacs using MSG-G5 (Multiple Orbit Almanac). In addition, there is an avenue for LunaNet nodes to distribute ephemeris information for Earth-centric GNSS constellations in support of receivers using weak signals from Earth-centric GNSS. The LNSP may disseminate GNSS ephemeris data using MSG-G23 (GNSS Augmentation).

3.2.3.6 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 (MSG-G10), information regarding spacecraft state estimation uncertainty and attitude/orientation (MSG-G11 or MSG-G1).

3.3 MESSAGING SERVICES

Messaging services provide a standard method for information messages to be transferred between a provider node and a user node or between two provider nodes using any of the applicable interfaces. Figure 16 illustrates the simplified protocol stack for messaging. Messaging applications send and receive messages through messaging servicing protocols which insert and extract the messages through any of the available interfaces. Messaging applications will be defined outside of this document and be able to use these standardized messaging servicing protocols to exchange the information required. The specific standards for messaging are still being determined. The messaging service in LunaNet 1.0 will be transported over the link layer (as described in [AD6], {LNIS-TBD-AD0006or via the AFS (as described in [AD1 Vol-A]).

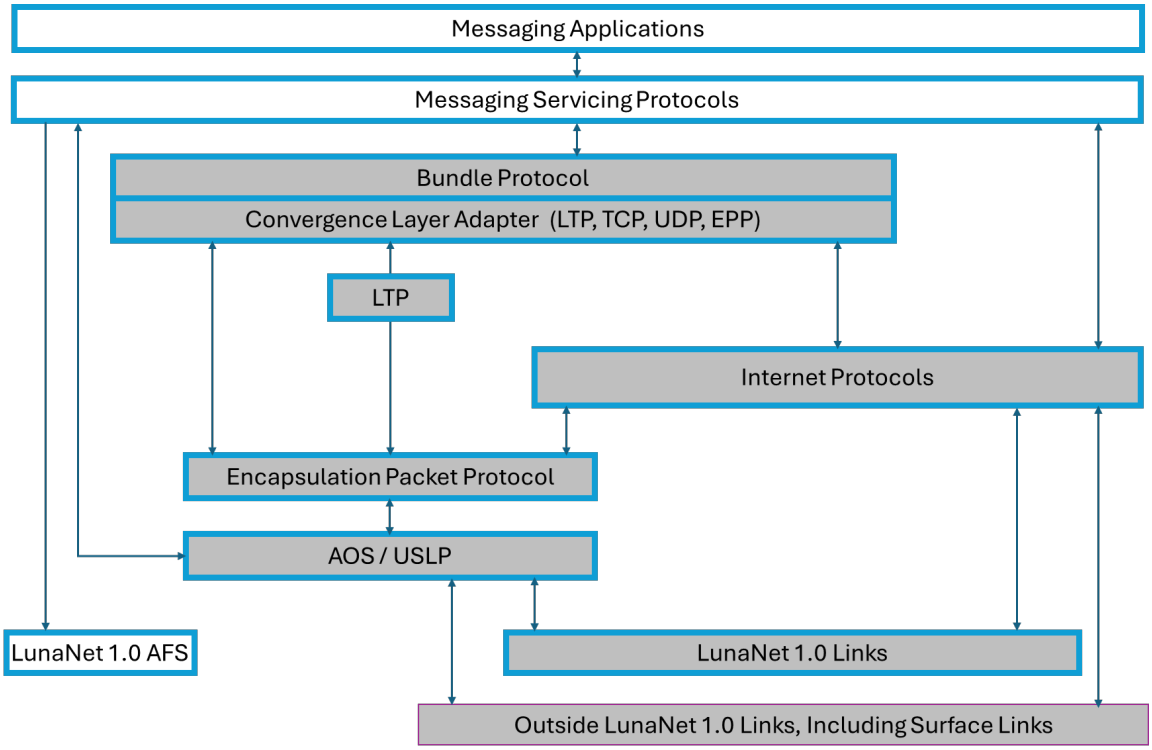

Figure 16: LunaNet Application Messaging Simplified Protocol Stack

The messaging service will be used to broadcast or exchange LunaNet messages defined in Table 5, regarding the LunaNet network, a particular LNSP, essential PNT session data, and updates such as: alerts, space weather and LunaSAR. Note that the messages will use the same physical links as the user data, with the link used dependent on the type of message (hence its intended use, size and priority) and the availability of the link. However, messages are not intended for user data flows. The number and type of LunaNet messages are expected to evolve over time. The Messaging Service standard, [AD3]{LNIS-TBD-AD0003}, will provide the details of how LunaNet messages are carried within the services and interfaces.

Use of the messaging service is shown below in Figure 17.

- Messages can be ‘pushed’ (normally via AFS but potentially also through a P2P link).
  - For example, MSG-G4 & MSG-G8 as defined in [AD1 Vol-A].
- Messages can be ‘pulled’ by sending a request message (not part of LunaNet 1.0) and then receiving a response message in return (either by a P2P link or the AFS link).
  - For example, request MSG-S18 & response MSG-S19 / MSG-S20 as defined in Table .

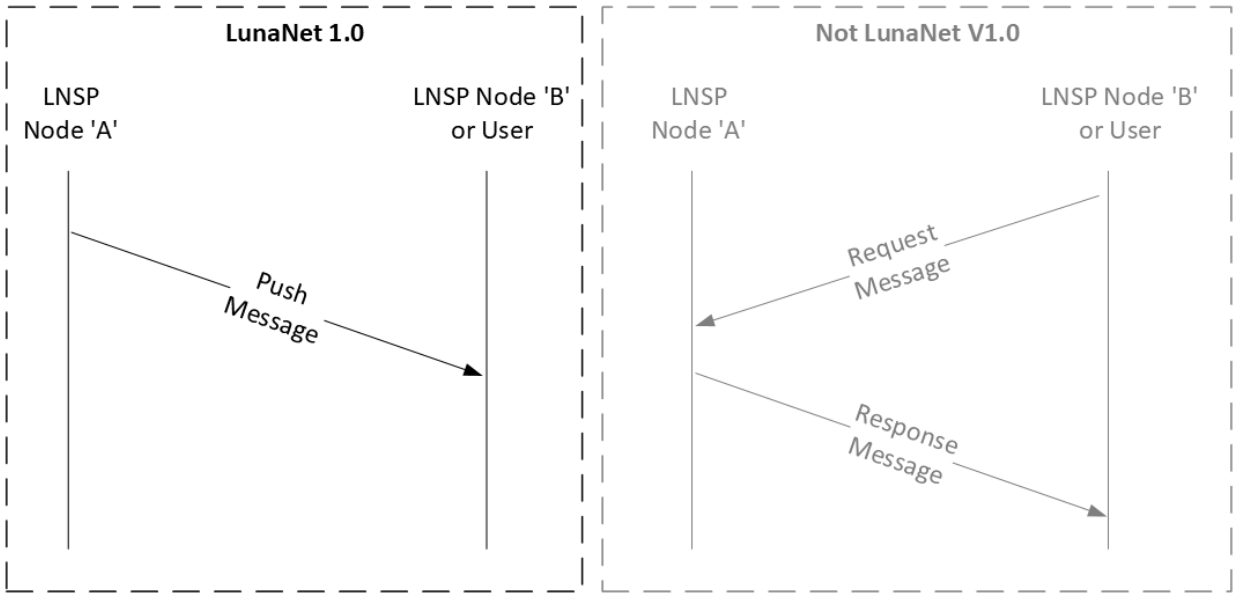

Figure 17: LNSP Node and User Exchange Messages using Messaging Services

Message formats, content, parameters, and association with each service and/or interface is provided within the Applicable Documents. An overview of the messages is provided in Table 5, along with a short description, and the applicability of the message to LunaNet 1.0. Messages are further defined in [AD3] with messages specific to AFS being defined in [AD1 Vol-A]. Messages that are not part of LunaNet 1.0 are included as placeholder only and will not be specified as part of LunaNet 1.0. These placeholders are indicated herein to identify the need for flexibility in LunaNet systems to accommodate evolving messages. As such, these placeholder messages are not identified as TBD/TBR.

Table 5: Message Identification, Applicable Documentation and LunaNet 1.0 Applicability

MSG ID	MSG Title	Description	LunaNet 1.0
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 (multiple) Antenna Properties, H&S (health and safety).	Yes
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.	Yes
MSG-G3	M(ultiple) Antenna Properties	Information about the transmission antenna properties (e.g.: antenna offset from CG (center of gravity) in body frame,	Yes

		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 (interface control document). 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	S(ingle) orbit Ephemeris & clock correction (Clock and Ephemeris Data – CED)	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 System Time (LST) to the LunaNet 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).	Yes
MSG-G5	M(ultiple) Orbit 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.	Yes
MSG-G6	S(ingle) Orbit 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.	No
MSG-G7	S(ingle) OrbitState / Location	Location Service information to user, whether on surface or in orbit.	No
MSG-G8	Time of transmission (ToT)	Time information provided at the defined edge of a synchronization symbol within the navigation message.	Yes
MSG-G9	Time and Frequency Synchronization (frame)	Time information provided to allow implementation of navigation services other than LANS or a dedicated CDMA signal.	No
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.	Yes
MSG-G11	S(ingle) Attitude 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.	Yes
MSG-G12	M(ultiple) AttitudeEphem	Attitude information of multiple satellites, e.g., the constellation of LNSP nodes.	No
MSG-G13	Observations	Information on metric tracking measurements (observations) performed by one entity that is forwarded to a separate entity.	Yes
MSG-G14	Conjunction	Announces a potential conjunction between lunar orbiters. This concept could be like the CCSDS standard for Conjunction Data Message exchanges.	No
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.	No

MSG-G16	Map Comprehensive	Full high resolution digital elevation map for specific lunar surface selenographic sector(s).	No
MSG-G17	Ancillary info	Basic data required for PNT, for example reference frames, additional coordinate transformations, lunar potential models, lunar ephemeris, lunar orientation parameters, covariance, and state transition matrix.	Yes
MSG-S18	Search and Rescue Alert	Alert from Search and Rescue beacon.	No
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.	No
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).	Yes (see Note-2)
MSG-G21	User Message Request	Request by user for specific message.	No
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.	No
MSG-G23	GNSS Augmentation	Augmentation information (e.g., GNSS satellite ephemeris/almanac) for Earth GNSS satellites. This information can be exploited by high-sensitivity GNSS receivers in cislunar space to support the use of Earth GNSS (i.e., to reduce the acquisition search space and provide the ephemeris if it cannot be decoded from the GNSS navigation message).	No
MSG-G24	Detection Alert	Used to broadcast an alert that must be disseminated to the users.	No
MSG-G25	Science Alert	Disseminates science-specific alert data.	No
MSG-G26	UIS Request	Request from user for services from an LNSP.	No
MSG-G27	UIS Response	Notification to user indicating response to the UIS Request.	No
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.	Yes
MSG-G29	FF Commands	Specific user commands or information needed rapidly by user, distributed via broadcast.	No
MSG-G30	Time Conversions	Time offset between LunaNet reference time (LRT) and other relevant time scales (e.g., UTC, LNSP System Time)	Yes
MSG-G31	Differential Corrections	Differential corrections (i.e., direct corrections or raw observables) provided by a local differential station.	Yes
MSG-G32	Coordinate Frame Conversions	Transformations needed to convert from one defined coordinate frame to another defined coordinate frame.	Yes

Note-1: 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.

Note-2: MSG-S20 is a LunaNet 1.0 item, but limited to reserving a bit allocation for LunaSAR Return Messages that are to be disseminated via AFS.

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 [AD3]. 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 6: Detection and Information Services

Service	Description	Required Interoperability Standards
LunaSAR	Determines user location and gathers critical user status	LunaSAR Message Content / Format Distress Message Prioritization Possible signal design

3.5 SERVICE ACCESS

Users will be able to access services through a variety of methods. Services may be scheduled by an Earth-based operations center, accessed following a process initiated by the user platform, or may be immediately accessed. All of these methods assume that a user has completed any necessary processes to be onboarded as a network user prior to the operational phase described here. Standardized link establishment processes or procedures may be required at the start of a service that apply to all methods of service access via space links. The information regarding the link establishment process for each interface will be defined in [AD1 Vol-B] {LNIS-TBD-AD0001VB}.

3.5.1 EARTH-BASED SCHEDULING SERVICE

Earth-based scheduled services are those where the request originates from the user's Earth-based mission control center or other terrestrial location 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. Earth-based scheduled services can be delivered to cislunar users via any of the user interfaces defined in LNIS (i.e. DWE, Proximity or Contingency). Standards for Earth-based scheduling of services will be considered in future updates of the LNIS.

3.5.2 USER INITIATED SERVICES

User Initiated Services (UIS) will allow users to request services for themselves over links between the user and an LNSP node. The implementation of the UIS process is anticipated to enhance overall operational efficiency by streamlining service acquisition through predefined protocols, reduce latency, and provide a more reliable and flexible infrastructure. This is expected to result in improved responsiveness to service requests, optimized resource utilization, and increased adaptability to dynamic scenarios.

Two UIS methods have been identified. Service Access via Hailing utilizes signaling over RF links, while Service Access via Messaging allows users to request services through service access requests

inserted in-band of an already existing link. Service Access via Hailing is specified further below. Service Access via Messaging has not yet been defined.

3.5.2.1 SERVICE ACCESS VIA HAILING

The Proximity-1 protocol provides a standardized method for establishing a communication session over a space proximity link between an orbiting relay and a space-based user asset and can facilitate UIS through hailing of the orbiting relay by the user asset. Section 4.1 of this document provides more information, including the application within LunaNet 1.0 of the forthcoming CCSDS 235.1 Space Communications Session Control book.

3.5.3 BROADCAST SERVICES

Broadcast services are a category of services which a user can access without scheduling or a UIS process. These services are limited to be within the coverage of a capable LNSP node.

3.5.3.1 AUGMENTED FORWARD SIGNAL (AFS)

AFS as a broadcast link is described for PNT purposes in Section 3.2 and [AD1 Vol-A]. Within the AFS message structure there are fields reserved for network access and scheduling information, serving as an entry point to the LNSP network. Users entering the service volume (see Figure 18) acquire the AFS signal and obtain a coarse state of services available. This capability enables LNSPs to provide users with important information and data. Given the ubiquitous nature of the service, it serves as a dissemination channel for relevant notifications and alerts via provision of standard messages (Section 3.3).

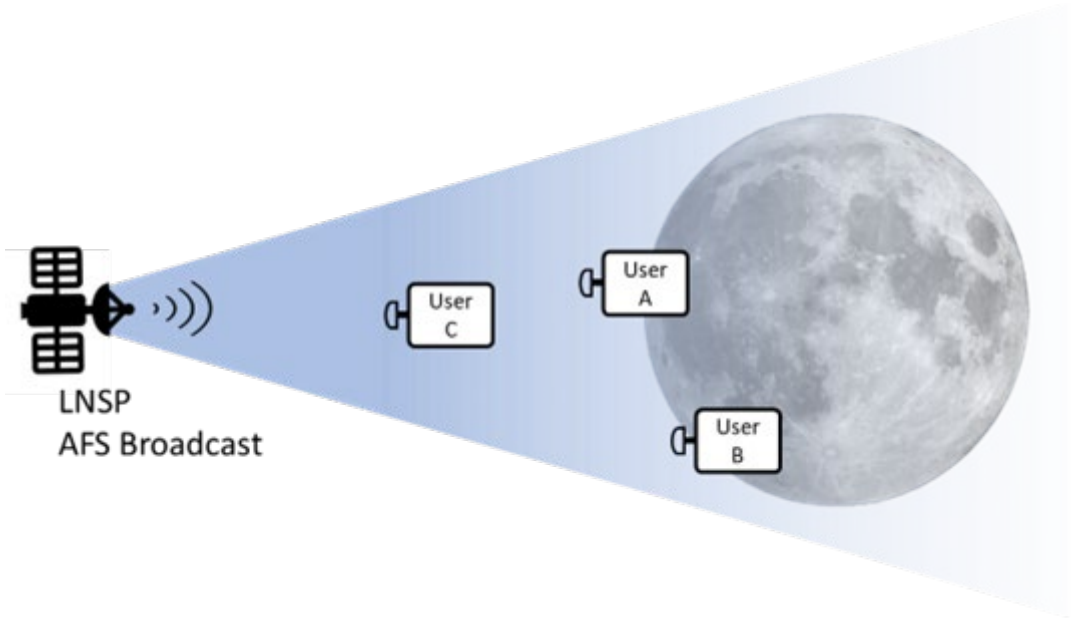

Figure 18: Augmented Forward Signal Provided by a Single LNSP Source to Multiple Users

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 and are required to confirm to the ITU Radio Regulations. Standards for optical link interfaces are TBD {LNIS-TBD-4001 }. Communications link frequency ranges specified in this document for LunaNet 1.0 are illustrated in

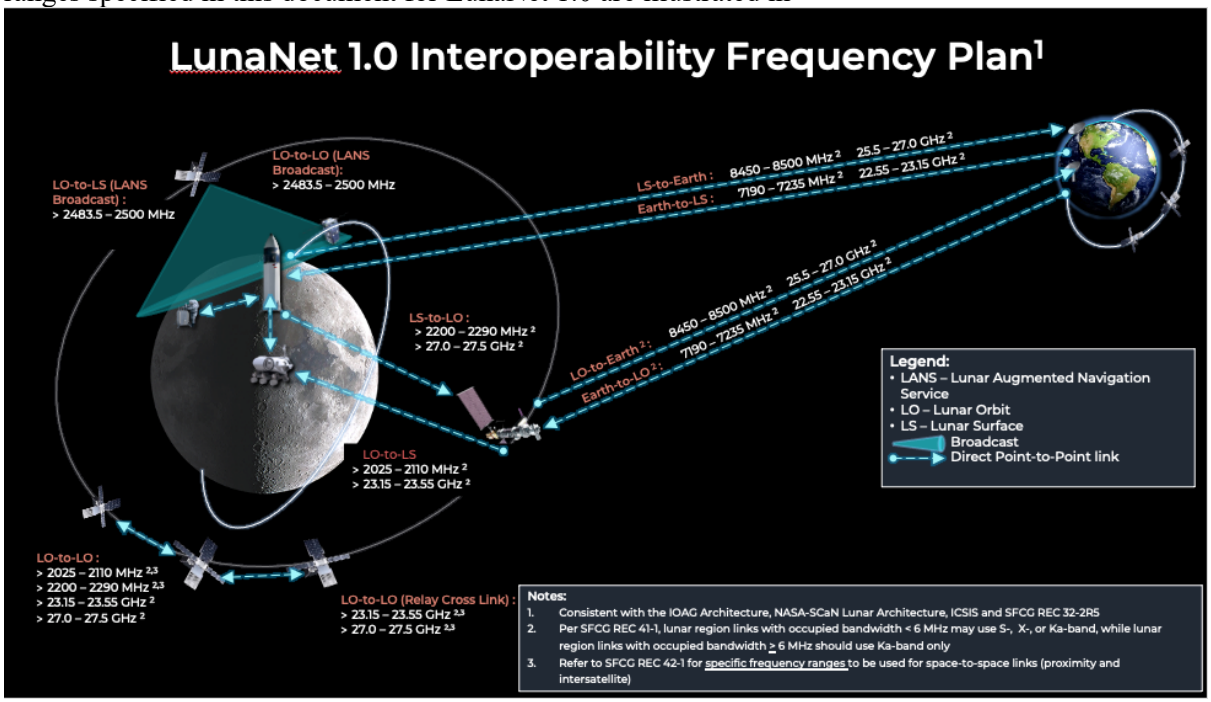

Figure 19. For reference, the full electromagnetic spectrum architecture for lunar region use based on the SFCG recommendations are illustrated in Figure 20.

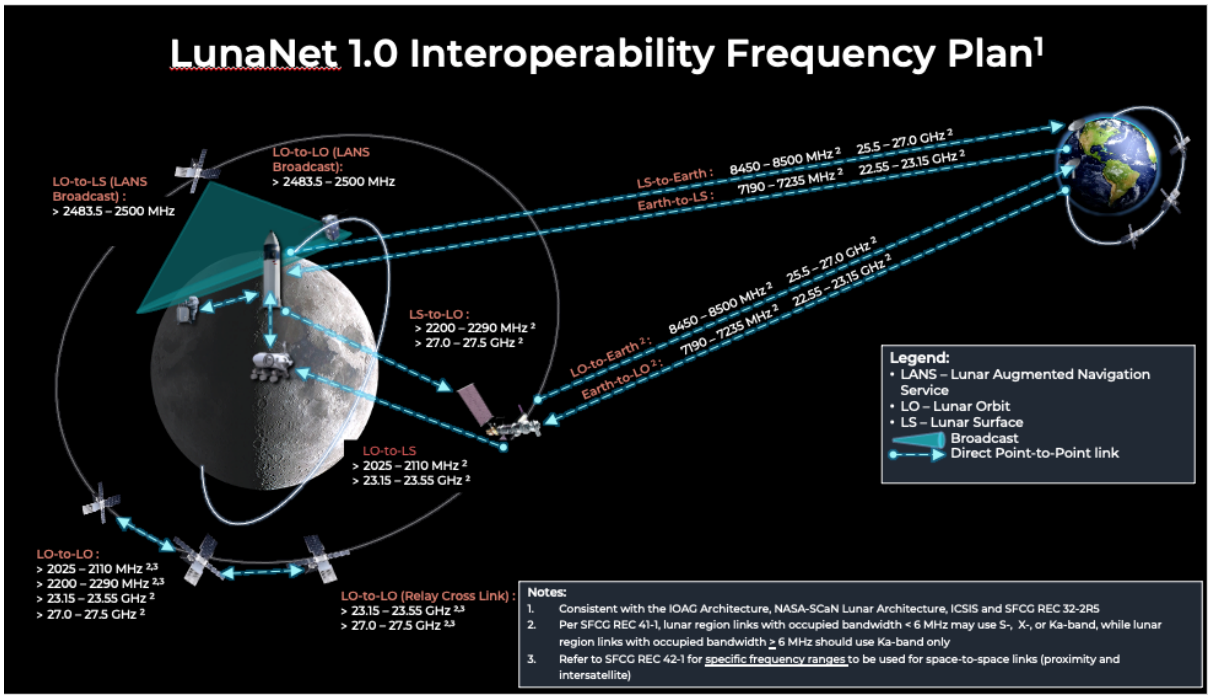

Figure 19: LunaNet 1.0 Interoperability Frequency Plan

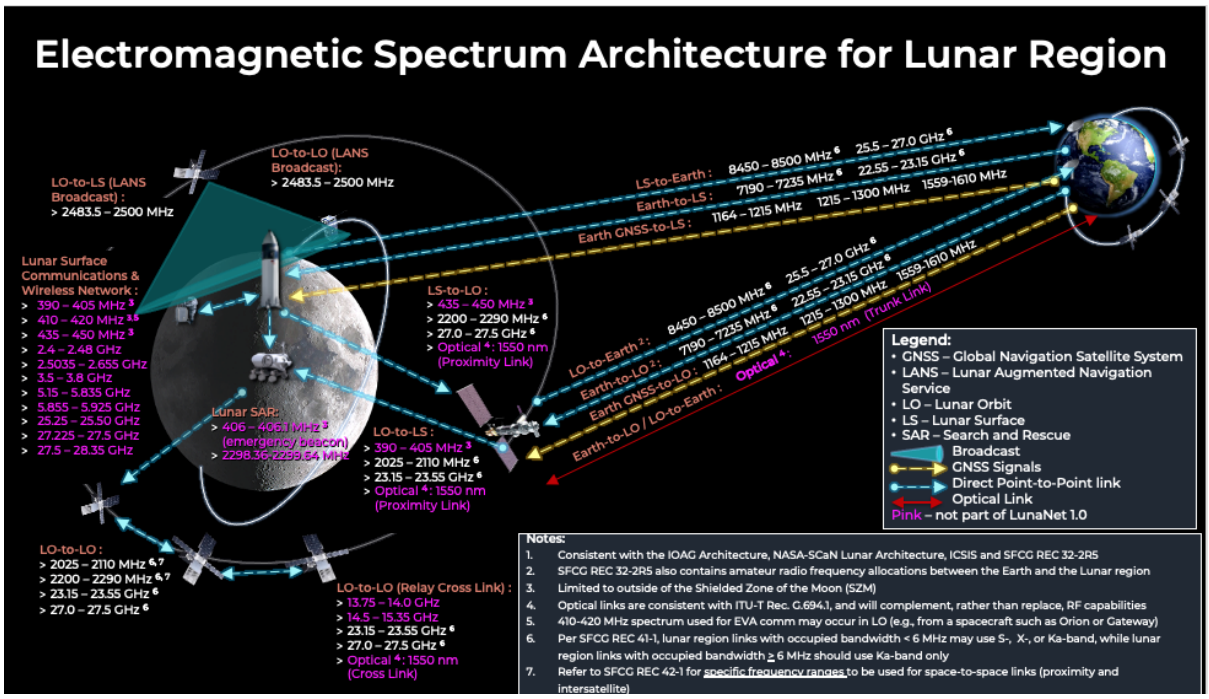

Figure 20: Electromagnetic Spectrum Architecture for Lunar Region

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,
    - These bands include 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.
    - The IOAG "Future Lunar Communication Architecture" (Final version 1.3; 31 January 2022) includes optical communications links. LNIS anticipates including optical links in the future but does not address them in this version.
- SFCG REC 42-1 specifies frequency ranges to be used for space-to-space links (proximity and intersatellite). The ranges stated in this document are general ranges.
- SFCG REC 43-1 provisionally identifies protection of the 2483.5 – 2500.0 MHz spectrum.
- The coded symbol rate is the rate with all encoding applied referenced at the input of the Bi-Phase-L converter (if used)/modulator including Attached Sync Marker (ASM)/Code Sync Marker (CSM) bits (see Figure 21).

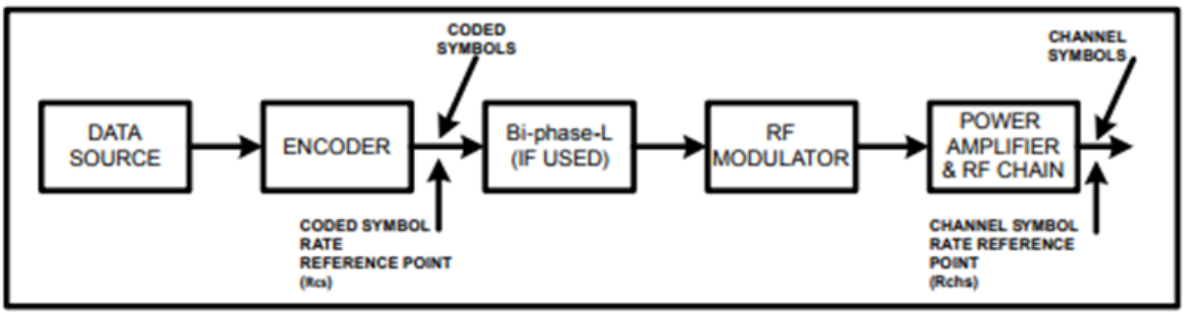

Figure 21: Coded Symbol Rate Reference Point Illustration

Currently, the band 2483.5 – 2500 MHz is allocated to Radio Navigation Satellite Service (RNSS) (broadcast PNT services).

4.1 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 . 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. A footnote indicates instances where interfaces shown in previous versions of this document and are maintained in this version for future ID use, as placeholders, but are not part of LunaNet 1.0. See Appendix B.4 Interfaces Expected in LunaNet 1.0 and footer notes from the tables in this section.

SFCG Recommendation 42-1 further specifies the frequency range, which is shared for use by space-to-space links (proximity and intersatellite). The ranges stated in this table are general ranges for the shared purpose. Please refer to this SFCG recommendation.

The CCSDS Proximity-1 protocol is currently being updated from the original UHF band and Mars application to S-band and K-band for lunar applications and beyond. As part of the updates, there will be a new separate 235.1 Space Communications Session Control published in the future, that will make use of the defined link establishment and user hailing mechanism for any proximity link, regardless of whether it applies the complete Proximity-1 standard or not, with the flexibility for demanded or negotiated link establishment. Specific application of CCSDS 235.1 for each LNIS proximity link will be addressed in [AD1 Vol-B]. The Session Control protocol can be applied to facilitate a pre-scheduled session where the orbiting relay hails the cislunar asset, or the case where the user asset hails the relay to request UIS. Rec SFCG 42-1 has the latest recommendation on hailing channel parameters for establishing these services.

Table 7: LNSP-User Proximity Interfaces Single Access

Frequency	ID	Modulation	Coded 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-O	Filtered OQPSK	Min: 1 Msps Max: 5 Msps	No	Higher order modulation for higher data rates, without ranging.
	PFS1d-G	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 High Data Rates w/ Ranging.
S-band 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-O	Filtered OQPSK	Min: 1 Msps Max: 5 Msps	No	Higher order modulation for higher data rates, without ranging.
	PRS1d-G	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 High Data Rates w/ Ranging.

K-band Forward 23.15-23.55 GHz	PFK1	(Filtered) BPSK	Min: 1 Msps Max: 2.048 Msps {LNIS-TBR-4013}	No	BPSK given as option for simplest, low-rate K-band system.
	PFK2[4]	DVB-S2, SCCC, or LDPC-VCM	Min: 1 Msps Max: {LNIS-TBR-4011}	No	VCM schemes enable spectrally efficient higher data rates.
	PFK3-O	Filtered OQPSK	Min: 1 Msps Max: {LNIS-TBR-4012}	No	OQPSK modulation common on existing K-band links.
	PFK3-G	GMSK	Min: 1 Msps Max: {LNIS-TBD-4027 }	No	Higher order modulation for higher data rates, without ranging.
	PFK4	GMSK+PN	Min: 1.5 Msps Max: {LNIS-TBD-4013}	PN Ranging	GMSK+PN High Data Rates w/ Ranging.
K-band Return 27.0-27.5 GHz	PRK1	(Filtered) BPSK	Min: 1 Msps Max: 2.048 Msps { LNIS-TBR-4014	No	BPSK given as option for simplest, low-rate K-band system.
	PRK2[4]	DVB-S2, SCCC, or LDPC-VCM	Min: 1 Msps Max: {LNIS-TBD-4015 }	No	VCM schemes enable spectrally efficient higher data rates.
	PRK3-O	Filtered OQPSK	Min: 1 Msps Max: {LNIS-TBD-4016}	No	OQPSK modulation common on existing K-band links.
	PRK3-G	GMSK	Min: 1 Msps Max: { LNIS-TBD-4029 }	No	Higher order modulation for higher data rates, without ranging.
	PRK4	GMSK+PN	Min: 1.5 Msps Max: {LNIS-TBD-4017}	PN Ranging	GMSK+PN High Data Rates w/ Ranging.

[4] This interface is not included in LunaNet 1.0.

[4] This interface is not included in LunaNet 1.0.

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	Coded Symbol Rate	Ranging	Summary
S-band Forward 2025-2110 MHz	PFS2[5]	SS-BPSK SS-UQPSK {LNIS-TBR-4005 }	{LNIS-TBR-4005 }	Spread spectrum PN	Spread spectrum PN w/ ranging, low spreading ratio for medium data rates.
S-band Return 2200-2290 MHz	PRS2[4]	SS-BPSK SQPN {LNIS-TBR-4008 }	{LNIS-TBD-4007}	Spread spectrum PN	Spread spectrum PN w/ ranging, low spreading ratio for medium data rates.
S-band Return 2200-2290 MHz Fc: {{LNIS-TBD-4008 }	PRS5[4]	SS-BPSK SQPN {LNIS-TBR-4010 }	{LNIS-TBD-4009 }	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	AFS	[AD1 Vol-A]	[AD1 Vol-A]	[AD1 Vol-A]	See Section 3.2.1.1 Lunar Augmented Navigation Service (LANS)

4.2 LNSP-USER DWE INTERFACES

A summary of the DWE signal interfaces is shown in Table 9[6]. DWE links are those between an Earth station LNSP and user Lunar vicinity assets, including assets on the lunar surface and in Lunar Orbit.

[4] This interface is not included in LunaNet 1.0.

[5] It is noted that CDMA based approaches may be required due to the limited bandwidth available for DWE in X-band or to operate according to Multiple Spacecraft per Aperture (MSPA) approaches. These are under consideration for inclusion in future versions of this document for LunaNet 1.0.

[6] It is noted that CDMA based approaches may be required due to the limited bandwidth available for DWE in X-band or to operate according to Multiple Spacecraft per Aperture (MSPA) approaches. These are under consideration for inclusion in future versions of this document for LunaNet 1.0.

In this document the special case of the link between a lunar relay orbiter and an Earth station is identified as the "trunk link." A trunk link exists in both the forward and return directions. LNSP assets should consider using these signal specifications for intra-network trunk links to enable interoperability for inter-network trunk links. 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**	**Coded 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: 10 Msps	PN Ranging	GMSK+PN 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.
X-band 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: 10 Msps	PN Ranging	GMSK+PN 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 {LNIS-TBR-4015 }	Frame Ranging	OQPSK (or GMSK) modulation common on existing K-band links.
	KU2		GMSK+PN	Min: 2 Msps Max: 50 Msps {LNIS-TBR-4016_}	PN Ranging	GMSK+PN High Data Rates w/ Ranging.
K-band Downlink 25.5-27.0 GHz	KD1		Filtered OQPSK or GMSK	Min: 2 Msps Max: 200 Msps {LNIS-TBR-4017 }	Frame Ranging	OQPSK (or GMSK) modulation common on existing K-band links.

4.3 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	Coded 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.

Proximity S-band 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.
DWE X-band 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.

4.4 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.

Table 11: LNSP–User Terrestrial Link Layer Service Interfaces

Service Interface ID	Interface Type	Applicable Documents
SLE RAF	Space Link Extension Return All Frames	[AD20] CCSDS 911.1-B-5
SLE RCF	Space Link Extension Return Channel Frames	[AD21] CCSDS 911.2-B-4
SLE FCLTU	Space Link Extension Forward CLTU	[AD22] CCSDS 912.1-B-4
N/A	Space Link Extension – Internet Protocol for Transfer Services	[AD23] CCSDS 913.1-B-2

CSTS FFS	Cross Support Transfer Service Forward Frame Service	[AD24] CCSDS 922.3-B-1

Network layer interfaces between terrestrial users and LNSP network layer services are described in [AD6]{LNIS-TBD-AD0006}.

4.5 LNSP-USER NETWORK LAYER INTERFACES

Some end-users may connect over types of physical links that are not specified within LNIS, but are passing routed network layer data otherwise compliant with LNIS network communications services. Figure 8 illustrates how the LNIS network layer protocols (BP and IP) are able to be carried over a variety of underlying types of links, including ones specified outside of LNIS. LNSPs can offer LunaNet network connectivity over such other types of physical links, if they support a valid LNSP-User network layer interface. Example cases include (but are not limited to):

- Surface users connected via UHF, Wi-Fi, or 3GPP links.
- Users connecting via wired links (e.g., Ethernet in a vehicle or habitat).
- Other bilaterally agreed proximity links or crosslinks between users and LNSPs

Table 12 below indicates network layer data units that an LNSP can route between users and other LunaNet network segments the LNSP interfaces to, based on addressing or endpoint IDs determined between the users and LNSP.

Table 12: LNSP-User Network Layer Interfaces

Network Service Type	Direction	Interface Protocol	Interface Data Units	Notes
Real-time IP	Forward or Return	IPv4	IPv4 Packets	For non-LNIS compliant data links, additional details and sub-IP support protocols (e.g. for encapsulation, address resolution, etc.) are out of scope of LNIS and must be bilaterally defined.
Real-time IP	Forward or Return	IPv6	IPv6 Packets	
DTN	Forward or Return	BPv7	BPv7 Bundles	Convergence layer adapter protocols might be bilaterally agreed between the LNSP and user.

Unlike these network layer interfaces that support routing; real-time link-layer services are intended to be provided only to users that interface directly over LNIS-compliant proximity links.

Further detail can be found in [AD6]. LNSP-User network layer interfaces will require security policies to manage connections in accordance with the LunaNet security specifications. LNSPs that implement alternative connectivity options are responsible for ensuring the security of those connections.

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. The interfaces between LNSPs are identified in section 6. Though there is some overlap between services and interfaces between LNSP and those between a LNSP and user, there are some additions that exist in order to allow multiple LNSPs to work together to provide the larger LunaNet infrastructure for use.

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 of this document.

6 LUNANET SERVICE PROVIDER TO LUNANET SERVICE PROVIDER SERVICES

6.1 LNSP A-LNSP B CROSSLINK INTERFACES

To allow end-to-end delivery of user data, cross-link interfaces shall support interfacing at the network layer, in accordance with section 5.1 . 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 the use of observables for self-navigation purposes. This section will cover the required interfaces between providers to ensure resilient services independent from Earth.

Table 13: LNSP–LNSP Crosslink Layer Interfaces

Interface Name	Interface Type	Targeted Frequency Range[3]	Modulation[4]	Coding[4]	Applicable Documents[2]
CFK1	Crosslink Forward[1]	23150-23200.7173 MHz and 23400.7173-23550 MHz	Filtered OQPSK and GMSK[2] {LNIS-TBD-AD0001VB}	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)	[AD9] CCSDS 131.0-B CCSDS 401.1-B-1[2]
CRK1	Crosslink Return[1]	27-27.16 GHz and 27.36-27.5 GHz	Filtered OQPSK and GMSK[2] {LNIS-TBD-AD0001VB}	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)	[AD9] CCSDS 131.0-B CCSDS 401.1-B-1[2]

[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. 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. 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.” CCSDS is working on but has not published, a volume specific for space-to-space links, CCSDS 401.1-B-1 Radio Frequency and Modulation Systems – Part 2 Intersatellite and Space-to-Space Links.

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

[4] Preliminary recommendations are SFCG Rec 42-1.

6.2 LNSP A-LNSP B DWE INTERFACES

These interfaces will follow the same standards as identified in 4.2 LNSP-User DWE Interfaces.

6.3 LNSP A-LNSP B TERRESTRIAL INTERFACES

These interfaces will follow the same standards as identified in section 4.4 LNSP-User Terrestrial Interfaces.

6.4 LNSP A-LNSP B NETWORK LAYER INTERFACES

Some LNSPs may inter-connect to one another over types of physical links that are not specified within LNIS, but that convey routed network layer data otherwise compliant with LNIS network communications services. LNSPs can provide LunaNet network connectivity to one another via such other types of physical links, if they support a valid LNSP-LNSP network layer interface. Example cases include (but are not limited to):

- Intersatellite crosslinks, specified outside of LNIS.
- Wired links between payloads onboard a vehicle or on the lunar surface.
- Wi-Fi, 3GPP, and other types of surface wireless links outside of LNIS.

The interface options for LNSP-to-LNSP network layer interfaces are the same as those for LNSP-User interfaces indicated in Table 13 in Section 6.1 prior.

Further detail can be found in [AD6]. LNSP-LNSP network layer interfaces will require security policies to manage connections in accordance with the LunaNet security specifications. LNSPs that implement alternative connectivity options are responsible for ensuring the security of those connections.

7 REFERENCES AND APPENDICES

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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
CCSDS	Consultative Committee for Space Data Systems
CD	Contingency Downlink
CDMA	Code Division Multiple Access
CFK	Cross Forward link K-band
CLPS	Commercial Lunar Payload Services
CLTU	Command Link Transmission Unit
CRK	Cross Return link K-band
CU	Contingency Uplink
DEM	Digital Elevation Map
DTE	Direct to Earth

Acronym	Description
DTN	Delay/Disruption Tolerant Networking
DVB-S2	Digital Video Broadcasting - Satellite - Second Generation
DWE	Direct with Earth
ECSS	Europeans Cooperation for Space Standardization
ESC	Exploration and Space Communication
EVA	Extravehicular Activity
GHz	Gigahertz
GMSK	Gaussian Minimum Shift Keying
GNSS	Global Navigation Satellite System
Hz	Hertz
ICAO	International Civil Aviation Organization
ICSIS	International Communication System Interoperability Standard
IETF	Internet Engineering Task Force
IMO	International Maritime Organization
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capability
IP	Internet Protocol
ksps	Kilo Symbols Per Second
LANS	Lunar Augmented Navigation Service
LDPC	Low Density Parity Check
LHCP	Left-Hand Circularly Polarized

Acronym	Description
LNSP	LunaNet Service Provider
LO	Lunar Orbit
LRT	LunaNet Reference Time
LS	Lunar Surface
LST	LNSP System Time
LTP	Licklider Transmission Protocol
MAR	Multiple-Access-Return
MHz	Megahertz
MOC	Mission Operations Center
Msps	Mega Symbols Per Second
NPD	NASA Policy Directives
NPR	NASA Procedural Requirements
NRZ-L	Nonreturn-To-Zero Level
OQPSK	Offset Quadrature Phase Shift Keying
P2P	Point to Point
PFC	Proximity Forward link Contingency
PFK	Proximity Forward link K-band
PFS	Proximity Forward link S-band
PN	Pseudo-Noise
PNT	Position, Navigation, and Timing
PRC	Proximity Return link Contingency

Acronym	Description
PRK	Proximity Return link S-band
PRS	Proximity Return link K-band
PVT	Position, Velocity, and Timing
RD	Reference Document
RF	Radio Frequency
RFC	Radio Frequency Compatibility
RHCP	Right-Hand Circularly Polarized
RNSS	Radio Navigation Satellite Service
SAR	Search and Rescue
SCaN	Space Communications and Navigation
SCCC	Serial Concatenated Convolutional Code
SFCG	Space Frequency Coordination Group
sps	Symbols Per Second
SS-BPSK	Spread Spectrum Binary Phase-Shift Keying
SZM	Shielded Zone of the Moon
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Reviewed
TCP/IP	Transmission Control Protocol/Internet Protocol
UDP	User Datagram Protocol
VCM	Variable Coding and Modulation

Acronym	Description
Wi-Fi	Wireless Fidelity

APPENDIX B SIGNAL INTERFACE DESCRIPTION

B.1 LNSP-USER PROXIMITY INTERFACES

This section defines the specifications for the signal formats across proximity links between LNSPs and users. SFCG Rec 42-1 specifies frequency ranges to be used for space-to-space links (proximity and intersatellite). The ranges stated in this document are general ranges. 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 $r = k/n$. [AD9] CCSDS 131.0-B Section 7.3 describes the LDPC 7/8 (8160, 7136) code. [AD11] CCSDS 231.0-B Section 4 describes the LDPC ½ (128, 64) and LDPC 1/2 (512, 256) codes. [AD9] 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. [AD9] 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. Although the initial capabilities must support Left-Hand Circularly Polarized (LHCP), LunaNet proximity services should be available on both 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 operates on a single polarization as defined in [AD1]. The MAR signal service (PRS5) has not been fully defined, including polarization.

B.2 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 coded 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 coded 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 [AD12] 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 [AD9] CCSDS 131.0-B- Section 7.4 for LDPC 1/2, 2/3, and 4/5.

[5] See [AD9] 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. NRZ-L for this modulation is not currently specified in [AD12] CCSDS 401.0-B but it was under consideration at CCSDS at the time of writing.

[10] The modulation index ranges provided here are a recommendation to ensure minimum interoperability of LNSPs.

[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. {LNIS-TBD-4025}

[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 refers 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 trunk links (> 200 Msps), higher order modulations and coding schemes specified in LNIS are recommended to maximize bandwidth efficiency. The VCM protocols specified within the LNIS (SCCC, DVB-S2, LDPC-VCM) or a subset of the codes in CCSDS 431.1-B-1 can be considered.

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 [AD12] CCSDS 401.0-B Section 2.2.8 and 2.3.2 for explanation of BPSK. [1] [2] [3]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	2 ksps ≤ Rs ≤ 2.048 Msps	
Modulation	(Filtered) BPSK	
Radiometric Ranging Options	No	-
Coding and Framing	Coded Symbol Rate 0.002 to 1.0Msps • LDPC r=½ (2048, 1024) bits • Uncoded, Message Size 16,384 bits Coded Symbol Rate 1.0 to 2.0 Msps • LDPC 1/2 (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] 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 [AD12] CCSDS 401.0-B Section 2.2.7 for explanation of PCM/PM/bi-phase-L. For Rs > 150 ksps, NRZ-L is recommended. [1] [9] [10] [11]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	48 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM Data Modulation Index: 0.4 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) bits • LDPC 2/3 (6144, 4096) bits • Convolutional, r=1/2, k=7 • Uncoded, Message Size 16,384 bits {LNIS-TBR-4011}	[4] [6] [7]
Applicable Documents	[AD9]CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] 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 [AD12] CCSDS 401.0-B Section 2.2.4 for explanation of PCM/PSK/PM. [1] [10] [11]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded 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) bits	[4] [6] [7]
Applicable Documents	[AD9]CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[8] [12]

Table B- 4: PFS1d-O - Proximity Forward S-Band (OQPSK) High-Rate Data Only

PFS1d-O - Proximity Forward S-Band (OQPSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	2025-2110 MHz	See [AD12] CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK. This signal allows higher data rates with bandwidth efficiency.
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	

Modulation	Filtered OQPSK	[1] [13] [14]
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (2048, 1024) bits • LDPC ½ (8192, 4096) bits • LDPC 2/3 (6144, 4096) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits {LNIS-TBR-4012}	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8] [12]

Table B- 5 : PFS1d-G - Proximity Forward S-Band (GMSK) High-Rate Data Only

PFS1dG - Proximity Forward S-Band (GMSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	2025-2110 MHz	See [AD12] CCSDS 401.0-B- Section 2.4.17A for explanation of GMSK. This signal allows higher data rates with bandwidth efficiency. [1] [13] [14]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (2048, 1024) bits • LDPC ½ (8192, 4096) bits • LDPC 2/3 (6144, 4096) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Convolutional, r=½, k=7	[4] [5] [6] [7]

	• Uncoded, Message Size 16,384 bits {LNIS-TBD-AD0005}	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8] [12]

Table B-6: 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 [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	GMSK+PN Ranging	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (2048, 1024) bits • LDPC ½ (8192, 4096) bits • LDPC 2/3 (6144, 4096) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8] [12]

Table B-7: PRS1a - Proximity Return S-Band Data Only

PRS1a - Proximity Return S-Band Data Only		
Parameter	Description	Notes
Frequency Range	2200-2290 MHz	See [AD12] CCSDS 401.0-B Section 2.3.2 for explanation of BPSK. [1] [2] [3] [13]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	2 ksps ≤ Rs ≤ 2.048 Msps	

Modulation	(Filtered) BPSK	
Radiometric Ranging Options	No	-
Coding and Framing	Coded Symbol Rate 0.002 to 1.0 Msps • LDPC r=½ (2048, 1024) bits • Uncoded, Message Size 16,384 bits Coded Symbol Rate 1.0 to 2.0 Msps • LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-8: 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 [AD12] CCSDS 401.0-B Sections 2.4.7 and 2.4.15A for explanation of PCM/PM/bi-phase-L. For Rs > 150 ksps, NRZ-L is recommended. [1] [9] [10] [11] [13] [14]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	48 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM Data Modulation Index: 0.4 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) bits	[4] [6] [7]

	• LDPC 2/3 (6144, 4096) bits • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits {LNIS-TBR-4011	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[8] [12]

Table B-9: 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 [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded 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) bits	[4] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[8] [12]

Table B-10: PRS1d-O - Proximity Return S-Band (OQPSK) High-Rate Data Only

PRS1dO - Proximity Return S-Band (OQPSK) High-Rate Data Only

Parameter	Description	Notes
Frequency Range	2200-2290 MHz	See [AD12] CCSDS 401.0-B- Section 2.4.17A for explanation of Filtered OQPSK. Allows for higher data rates with bandwidth efficiency. [1] [13]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	Filtered OQPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (2048, 1024) bits • LDPC ½ (8192, 4096) bits • LDPC 2/3 (6144, 4096) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits {LNIS-TBR-4012}	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8] [12]

Table B-11: PRS1d-G - Proximity Return S-Band (GMSK) High-Rate Data Only

PRS1dG - Proximity Return S-Band (GMSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	2200-2290 MHz	See [AD12] CCSDS 401.0-B- Section 2.4.17A for explanation of GMSK. Allows for higher data rates with bandwidth efficiency. [1] [13]
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (2048, 1024) bits • LDPC ½ (8192, 4096) bits	[4] [5] [6] [7]

	• LDPC 2/3 (6144, 4096) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Convolutional, r=½, k=7 • Uncoded, Message Size 16,384 bits {LNIS-TBD-AD0005}	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8] [12]

Table B-12: 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 [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 5 Msps	
Modulation	GMSK+PN Ranging	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (2048, 1024) bits • LDPC ½ (8192, 4096) bits • LDPC 2/3 (6144, 4096) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8] [12]

Table B-13: 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 [AD12] 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	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 2.048 Msps {LNIS-TBR-4013}	
Modulation	(Filtered) BPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-14: PFK2 - Proximity Forward K-band Variable Coding and Modulation

PFK2 - Proximity Forward K-band Variable Coding and Modulation – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
Frequency Range	23.15-23.55 GHz	See [AD12] CCSDS 401.0-B Section 2.4.23 and CCSDS 431.1-B for explanation of DVB-S2 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	
Coded Symbol Rate	1 Msps ≤ Rs ≤ {LNIS-TBD-4011 Msps	
Modulation	DVB-S2 or SCCC or LDPC-VCM	
Radiometric Ranging Options	No	
Coding and Framing	{LNIS-TBD-4026}	-
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

PFK2 - Proximity Forward K-band Variable Coding and Modulation – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
	CCSDS 131.3-B CCSDS 431.1-B CCSDS 131.2-B	

Table B-15: PFK3-O - Proximity Forward K-band (OQPSK) High-Rate Data Only

PFK3-O - Proximity Forward K-band (OQPSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	23.15-23.55 GHz	See [AD12] CCSDS 401.0-B Section 2.4.21A for explanation of Filtered OQPSK. Allows spectrally efficient high data throughputs with simpler implementation than VCM. [13] [14] [15]
Polarization	LHCP and/or RHCP	
Coded Symbol Rate	1 Msps ≤ Rs ≤ {LNIS-TBD-4012} Msps	
Modulation	Filtered OQPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-16: PFK3-G - Proximity Forward K-band (GMSK) High-Rate Data Only

PFK3-G - Proximity Forward K-band (GMSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	23.15-23.55 GHz	See [AD12] CCSDS 401.0-B Section 2.4.21A for explanation of GMSK. Allows spectrally efficient high data throughputs with simpler implementation than VCM. [13] [14] [15]
Polarization	LHCP and/or RHCP	
Coded Symbol Rate	1 Msps ≤ Rs ≤ { LNIS-TBD-4027} Msps	
Modulation	GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits	[4] [5] [6] [7]

	• LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-17: 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 [AD12] 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	
Coded Symbol Rate	1.5 Msps ≤ Rs ≤ {LNIS-TBD-4013}	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-18: 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 [AD12] 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	
Coded Symbol Rate	1 Msps ≤ Rs ≤ 2.048 Msps {LNIS-TBR-4014}	
Modulation	(Filtered) BPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits	[4][5][6][7]

PRK1 - Proximity Return K-band Data Only		
Parameter	Description	Notes
	• LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-19: PRK2 - Proximity Return K-band Variable Coding and Modulation

PRK2 - Proximity Return K-band Variable Coding and Modulation – Not LunaNet 1.0 Item		
Parameter	Description	Notes
Frequency Range	27.0-27.5 GHz	See [AD12] CCSDS 401.0-B Section 2.4.23 and CCSDS 431.1-B for explanation of DVB-S2 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	
Coded Symbol Rate	1 Msps ≤ Rs ≤ {LNIS-TBD-4015 } Msps	
Modulation	DVB-S2 or SCCC or LDPC-VCM	
Radiometric Ranging Options	No	
Coding and Framing	{LNIS-TBD-4028}	-
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B CCSDS 131.3-B CCSDS 431.1-B CCSDS 131.2-B	[8]

Table B-20: PRK3-O - Proximity Return K-band (OQPSK) High-Rate Data Only

PRK3-O - Proximity Return K-band (OQPSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	27.0-27.5 GHz	See [AD12] 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	
Coded Symbol Rate	1 Msps ≤ Rs ≤ {LNIS-TBD-4016} Msps	
Modulation	Filtered OQPSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits	[4] [5] [6] [7]

	• LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-21: PRK3-G - Proximity Return K-band (GMSK) High-Rate Data Only

PRK3-G - Proximity Return K-band (GMSK) High-Rate Data Only		
Parameter	Description	Notes
Frequency Range	27.0-27.5 GHz	See [AD12] 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	
Coded Symbol Rate	1 Msps ≤ Rs ≤ {LNIS-TBD-4029 }Msps	
Modulation	GMSK	
Radiometric Ranging Options	No	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	[4] [5] [6] [7]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

Table B-22: 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 [AD12] 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	
Coded Symbol Rate	1.5 Msps ≤ Rs ≤ {LNIS-TBD-4017} Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 2/3 (24576, 16384) bits	[4] [5] [6] [7]

	• LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits • Uncoded, Message Size 16,384 bits	
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[8]

B.3 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: Standard maximum bandwidth for spread spectrum S-band signal is 6.16 MHz. This allows a chip rate of ~3 Mcps. See [AD9] CCSDS 131.0-B Section 7.4 for LDPC 1/2, 2/3, and 4/5.

[1] 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.

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

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

[4] 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-23: PFS2 - Proximity Forward S-band Medium Rate w/ Ranging

PFS2 - Proximity Forward S-band Medium Rate w/ Ranging – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
Frequency Range	2025-2110 MHz Fixed frequency assignments are {LNIS-TBD-4004}	The intent of this signal is a medium data rate signal with spread spectrum PN ranging and user specific PN code. Differentiated from AFS that utilizes relay specific PN codes for broadcast service. Allows for higher data rates than AFS, and signal parameters could be modified to some extent for individual users. [1] Not a LunaNet 1.0 Item
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	Coded Symbol & Chip Rates are {LNIS-TBD-4005}	
Modulation	SS-BPSK CDMA (~3Mcps) or SS-UQPSK {LNIS-TBR-4005}	
Radiometric Ranging Options	Yes, details are {LNIS-TBD-4030}	
Coding and Framing	LDPC ½ (2048, 1024) bits	
Applicable Documents	[AD14] CCSDS 415.1-B [AD9] CCSDS 131.0-B	

Table B-24: PRS2 - Proximity Return S-Band Spread Spectrum

PRS2 - Proximity Return S-Band Spread Spectrum – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
Frequency Range	2200-2290 MHz Fixed frequency assignments are {LNIS-TBD-4006}	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] Not a LunaNet 1.0 Item
Polarization	LHCP mandatory for interoperability, RHCP capability recommended, see note E	

PRS2 - Proximity Return S-Band Spread Spectrum – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
Coded Symbol Rate	Coded Symbol & Chip Rates are {LNIS-TBD-4007}	
Modulation	SS-BPSK CDMA (~3Mcps) or SQPN {LNIS-TBR-4008}	
Radiometric Ranging Options	Yes, details are {LNIS-TBD-4031}	
Coding and Framing	LDPC ½ (2048, 1024) bits	
Applicable Documents	[AD14] CCSDS 415.1-B [AD9] CCSDS 131.0-B	

Table B-25: AFS- Proximity Forward S-band Augmented Forward Signal

Augmented Forward Signal AFS - Proximity Forward S-band		
Parameter	Description	Notes
Frequency Range	2483.5-2500 MHz, Fc = 2492.028 MHz	See Lunar Augmented Navigation Service (LANS) The PFS5 ID, used in previous versions to indicate the AFS, has been retired in this version. The Augmented Forward Signal is now simply referred to as AFS.
Coded Symbol Rate	500 sps	
Modulation	See [AD1 Vol-A]	
Radiometric Ranging Options	Yes	
Coding and Framing	AFS Structure [AD1 Vol-A]	
Applicable Documents	[AD1 Vol-A]	

Table B-26: PRS5 - Proximity Return S-Band Multiple Access Return (MAR)

Multiple Access Return (MAR) - PRS5 - Proximity Return S-Band – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
Frequency Range	2200-2290 MHz Fixed frequency assignments are {LNIS-TBD-4008}	Low rate, many users multiple access return with ranging. [1] Not a LunaNet 1.0 Item
Polarization	{LNIS-TBD-4032}	
Coded Rate	Coded Symbol & Chip Rates are {LNIS-TBD-4009}	
Modulation	SS-BPSK CDMA (~3Mcps) or SQPN {LNIS-TBR-4010}	
Radiometric Ranging Options	Yes, details are {LNIS-TBD-4033}	
Coding and Framing	{LNIS-TBD-4020}	

Multiple Access Return (MAR) - PRS5 - Proximity Return S-Band – Not a LunaNet 1.0 Item		
Parameter	Description	Notes
Applicable Documents	[AD14] CCSDS 415.1-B [AD9] CCSDS 131.0-B	

B.4 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 $r = k/n$. [AD9] CCSDS 131.0-B Section 7.3 describes the LDPC 7/8 (8160, 7136) code [AD11] CCSDS 231.0-B Section 4 describes the LDPC ½ (128, 64) and LDPC ½ (512, 256) codes. [AD9] 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. [AD9] 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. NRZ-L for this modulation is not currently specified in [AD12] CCSDS 401.0-B but it was under consideration at CCSDS at the time of writing.
[2] The modulation index ranges provided here are a recommendation to ensure minimum interoperability of LNSPs.
[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 [AD11] CCSDS 231.0-B – for description of LDPC short codes (128, 64) & (512, 256).
[6] See [AD9] CCSDS 131.0-B- Section 7.4 for a description of LDPC 1/2, 2/3, and 4/5.
[7] See [AD9] 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 [AD9]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 refers 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. {LNIS-TBD-4025 }

[12] For high throughput K-band trunk links (> 200 Msps), higher order modulations and coding schemes specified in LNIS are recommended to maximize bandwidth efficiency. The VCM protocols specified within the LNIS (SCCC, DVB-S2, LDPC-VCM) or a subset of the codes in CCSDS 431.1-B-1 can be considered.

[13] Ranging parameters must be selected in line with the guidance in CCSDS 414.0-G-2 such that spectrum limits are not violated.

Table B-27: 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 [AD12] 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	
Coded Symbol Rate	64 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM/bi-phase-L or PCM/PM/NRZ-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) bits • LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[5] [6] [7] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD11] CCSDS 231.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10]

Table B-28: 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 [AD12] CCSDS 401.0-B- Section 2.4.22A for an explanation of GMSK+PN Allows bandwidth efficient higher data rates with simultaneous ranging. [13]
Polarization	LHCP and/or RHCP	
Coded Symbol Rate	150 ksps ≤ Rs ≤ 10 Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6] [7] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10] [11]

Table B-29: 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 [AD12] 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	
Coded 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) bits • LDPC ½ (2048, 1024) bits • Uncoded, Message Size 16,384 bits	[5] [6] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD11] CCSDS 231.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10]

Table B- 30: 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 [AD12] 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	
Coded Symbol Rate	128 ksps ≤ Rs ≤ 10 Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	

Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6] [7] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[10] [11]

Table B-31: 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 [AD12] 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	
Coded Symbol Rate	64 ksps ≤ Rs ≤ 1.024 Msps	
Modulation	PCM/PM/bi-phase-L or PCM/PM/NRZ-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) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6] [7] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10] [11]

Table B-32: 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 [AD12] CCSDS 401.0-B- Section 2.4.22A for an explanation of GMSK+PN Allows bandwidth efficient higher data rates with simultaneous ranging. [13]
Polarization	LHCP and/or RHCP	
Coded Symbol Rate	150 ksps ≤ Rs ≤ 10 Msps	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	

Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6] [7] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10] [11]

Table B- 33: 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 [AD12] 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	
Coded 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) bits • Uncoded, Message Size 16,384 bits	[6] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10]

Table B-34: 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 [AD12] 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	
Coded Symbol Rate	128 ksps ≤ Rs ≤ 10 Msps	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	No	

XD4 - X-band Downlink High-Rate Data Only		
Parameter	Description	Notes
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6] [7] [8] [9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[10]

Table B-35: 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 [AD12] 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	
Coded Symbol Rate	2 Msps ≤ Rs ≤ 50 Msps {LNIS-TBR-4015 }	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	Frame ranging [RD24, RD25]	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6][7][8][9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[10][11]

Table B-36: 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 [AD12] 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	
Coded Symbol Rate	2 Msps ≤ Rs ≤ 50 Msps {LNIS-TBR-4016}	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	

KU2 - K-band Uplink High Data w/ Ranging		
Parameter	Description	Notes
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 (8160, 7136) bits	[6][7][8][9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10] [11]

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Table B-37: 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 [AD12] 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	
Coded Symbol Rate	2 Msps ≤ Rs ≤ 200 Msps {LNIS-TBD-AD0006}	
Modulation	Filtered OQPSK or GMSK	
Radiometric Ranging Options	Frame ranging [RD24, RD25] Not a LunaNet 1.0 option	
Coding and Framing	• LDPC ½ (32768, 16384) bits • LDPC 4/5 (20480, 16384) bits • LDPC 7/8 Rate (8160, 7136) bits	[6][7][8][9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B	[10]

Table B-38: 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 [AD12] 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	
Coded Symbol Rate	2 Msps ≤ Rs ≤ 200 Msps {LNIS-TBD-AD0003}	
Modulation	GMSK+PN	
Radiometric Ranging Options	Yes	
Coding and Framing	• LDPC ½ Rate (32768, 16384) bits • LDPC 4/5 Rate (20480, 16384) bits • LDPC 7/8 Rate (8160, 7136) bits	[6][7][8][9]
Applicable Documents	[AD9] CCSDS 131.0-B [AD12] CCSDS 401.0-B [AD13] CCSDS 414.1-B	[10][11]

B.5 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 coded 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 coded 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 coded symbol rate or a slightly higher coded 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 $r = k/n$. [AD11] 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.

[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 [AD11]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 [AD9] CCSDS 131.0-B-5 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 {LNIS-TBD-4025 }.

Table B-39 39: PFC1a - Proximity Forward S-band Contingency

PFC1a - Proximity Forward S-band Contingency		
Parameter	Description	Notes
Frequency Range	2025-2110 MHz	See [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded 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) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6]

Table B-40: PFC1b - Proximity Forward S-band Contingency

PFC1b - Proximity Forward S-band Contingency		
Parameter	Description	Notes
Frequency Range	2025-2110 MHz	See [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded Symbol Rate	250 sps	
Modulation	PCM/PSK/PM+NRZ-L	

PFC1b - Proximity Forward S-band Contingency		
Parameter	Description	Notes
	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	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6]

Table B-41: PRC1a - Proximity Return S-band Contingency

PRC1a - Proximity Return S-band Contingency		
Parameter	Description	Notes
Frequency Range	2200-2290 MHz	See [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded 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) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6][7]

Table B-42: PRC1b - Proximity Return S-band Contingency

PRC1b - Proximity Return S-band Contingency		
Parameter	Description	Notes
Frequency Range	2200-2290 MHz	See [AD12] 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 mandatory for interoperability, RHCP capability recommended, see note E	
Coded 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) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6][7]

Table B-43: CU1 - X-band Uplink Contingency

CU1 - X-band Uplink Contingency		
Parameter	Description	Notes
Frequency Range	7190-7235 MHz	See [AD12] 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	
Coded 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) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6]

Table B-44: CU2 - X-band Uplink Contingency

CU2 - X-band Uplink Contingency		
Parameter	Description	Notes
Frequency Range	7190-7235 MHz	See [AD12] 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	
Coded 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	

CU2 - X-band Uplink Contingency		
Parameter	Description	Notes
	Ranging Modulation Index: 0.2 to 1.4 radians (peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (512, 256) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6]

Table B-45: CD1 - X-band Downlink Contingency

CD1 - X-band Downlink Contingency		
Parameter	Description	Notes
Frequency Range	8450-8500 MHz	See [AD12] 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	
Coded 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) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6] [7]

Table B-46: CD2 - X-band Downlink Contingency

CD2 - X-band Downlink Contingency		
Parameter	Description	Notes
Frequency Range	8450-8500 MHz	See [AD12] 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	
Coded 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	

CD2 - X-band Downlink Contingency		
Parameter	Description	Notes
	Ranging Modulation Index: 0.2 to 1.0 radians (Peak) Chip rate: up to 4 Mcps	
Coding and Framing	• LDPC ½ (512, 256) bits	[3][4][5]
Applicable Documents	[AD12] CCSDS 401.0-B [AD11] CCSDS 231.0-B	[6] [7]

B.5 PROXIMITY INTERFACES EXPECTED IN LUNANET 1.0

The following Table B-47 presents a summary of the signal interfaces described in this Appendix. This table indicates to the best of knowledge at the moment of publication of this document version, which interfaces are expected to be provided. An “X” indicates interfaces common amongst at least two LunaNet Service Providers.

Table B-47: Services Identified in LunaNet 1.0 – {LNIS-TBD-AB0001}

Signal	Modulation	Ranging	Common provider interface in LunaNet 1.0
PFS1a / PRS1a	Filtered BPSK	No	X
PFS1b / PRS1b	PCM/PM	PN Ranging	X
PFS1c / PRS1c	PCM/PSK/PM	PN Ranging	X
PFS1d-O / PRS1d-O	Filtered OQPSK	No	{LNIS-TBD-AB0001}
PFS1d-G / PRS1d-G	GMSK	No	{LNIS-TBD-AB0001}
PFS1e / PRS1e	GMSK+PN	PN Ranging	{LNIS-TBD-AB0001}
AFS	AFS[AD1 Vol-A]		X
PFK1 / PRK1	Filtered BPSK	No	X
PFK3-O/ PRK3-O	Filtered OQPSK	No	X
PFK3-G / PRK3-G	GMSK	No	{LNIS-TBD-AB0001}
PFK4 / PRK4	GMSK+PN	PN Ranging	{LNIS-TBD-AB0001}
CFK1/CRK1	Filtered OQPSK and GMSK	PN Ranging	{LNIS-TBD-AB0001}

APPENDIX C PNT SERVICE TO LINK MAPPING

Table C-1 and Table C-2 below provide a relationship of PNT services according with the descriptions provided in Section 3.2, with the proximity link interfaces defined in Appendix B.

Table C-1: Proximity Link Supporting Signals

Services	Band-Direction	S-Forward								K-Forward			
	Interface ID	PFS1a	PFS1b	PFS1c	PFS1d	PFS1e	AFS	PFC1a	PFC1b	PFK1	PFK2	PFK3	PFK4
LANS							X						
1-Way Doppler Reference		O	O	O	O	O	X	O	O	O	O	O	O
2-Way Doppler Measurements		O	O	O	O	O		O	O	{LNIS-TBD-AC0001}			
2-Way Range Measurements			O	O		O		O	O				{LNIS-TBD-AC0002}
1-Way Doppler Measurements													

[1] "O" indicates the signal supports the ability to provide the service.
[2] "X" indicates it is mandatory for the signal to provide the service.

Table C-2: Proximity Link Supporting Signals

Services	Band-Direction	S-Return							K-Return			
	Interface ID	PRS1a	PRS1b	PRS1c	PRS1d	PRS1e	PFC1a	PFC1b	PFK1	PFK2	PFK3	PFK4
LANS												
1-Way Doppler Reference												
2-Way Doppler Measurements		O	O	O	O	O	O	O	{LNIS-TBD-AC0001}			
2-Way Range Measurements			O	O		O	O	O				{LNIS-TBD-AC0002}
1-Way Doppler Measurements		O	O	O	O	O	O	O	O	O	O	O

[1] "O" indicates the signal supports the ability to provide the service.
[2] "X" indicates it is mandatory for the signal to provide the service.

APPENDIX DSECTION MAPPING BETWEEN LNIS V4 AND V5

Mapping of previous LNIS versions to this current version can be found in Table D-1. The colors identify section hierarchy within the current version of the document. The items removed from the prior LNIS versions are grey.

Table D-1: Section Mappings Between LNIS Versions

Section Title	LNIS v5 Final	LNIS v5 Draft	LNIS v4
Introduction	**1**	**1**	**1**
Purpose	1.1	1.1	1.1
Scope	1.2	1.2	1.2
Security Considerations	1.3	1.3	1.3
Applicable Documents	1.4	1.4	8
LunaNet Interoperability Overview	**2**	**2**	**2**
LunaNet Reference Time	2.1	N/A	N/A
User Services	**3**	**3**	**3**
Communications Services	3.1	3.1	3.1
Real-Time Communications Services	3.1.1	3.1.1	3.1.1
Real-Time Link Layer Communications Services	3.1.1.1	3.1.1.1	3.1.1.1
Real-Time Network Layer Communications Services	3.1.1.2	3.1.1.2	3.1.1.2
DTN Network Communications Services	3.1.2	3.1.2 Store-and-Forward Communications Services	
Communications Services Address and ID Registration	3.1.3	(Messaging Services moved to 3.3)	
Position, Navigation, and Timing Services	3.2	3.2	3.2
Broadcast Service	3.2.1	N/A	N/A
Lunar Augmented Navigation Service	3.2.1.1	3.2.2	3.2.2
Direct Link Services	3.2.2	N/A	N/A
LNSP One-Way Doppler Reference	3.2.2.1	3.2.1.1	3.2.1.1

Section Title	LNIS v5 Final	LNIS v5 Draft	LNIS v4
LNSP Two-Way Doppler Measurement	3.2.2.2	3.2.4.1	3.2.4.1
LNSP Two-Way Range Measurement	3.2.2.3	3.2.4.2	3.2.4.2
LNSP One-Way Doppler Measurement	3.2.2.4	3.2.3.1	3.2.3.1
Supplemental Navigation Services	3.2.3	3.2.6	3.2.6
Lunar Reference Frame Related Messages	3.2.3.1	3.2.6.1	3.2.6.1
LunaNet Reference Time	3.2.3.2	3.2.6.2	3.2.6.2
Lunar Potential Model	3.2.3.3	3.2.6.3	3.2.6.3
Lunar Orientation Parameters	3.2.3.4	3.2.6.4	3.2.6.4
Constellation Orbital Parameters	3.2.3.5	3.2.6.5	3.2.6.5
Asset Specific Parameters	3.2.3.6	3.2.6.8	3.2.6.8
Messaging Services	3.3	3.3	3.1.3
Detection and Information Services	3.4	3.4	3.3
Service Access	3.5	3.6	3.5
Earth-based Scheduling Service	3.5.1	3.6.1	3.5.1
User Initiated Services	3.5.2	3.6.2	3.5.2.3
Broadcast Services	3.5.3	N/A	N/A
Augmented Forward Signal (AFS)	3.5.3.1	3.6.4.1	3.5.2.1
LunaNet Service Provider to User Interfaces	**4**	**4**	**4**
LNSP-User Proximity Interfaces	4.1	4.2	4.2
LNSP-User DWE Interfaces	4.2	4.3	4.3
LNSP-User Contingency Interfaces	4.3	4.4	N/A
LNSP-User Terrestrial Interfaces	4.4	4.5	4.4
LNSP-User Network Layer Interfaces	4.5	N/A	N/A
LunaNet Service Provider to LunaNet Service Provider Services	**5**	**5**	**5**
LNSP A-LNSP B Communications Services	5.1	5.1	5.1
LNSP A-LNSP B PNT Services	5.2	5.2	5.2

Section Title	LNIS v5 Final	LNIS v5 Draft	LNIS v4
LunaNet Service Provider to LunaNet Service Provider Interfaces	**6**	**6**	**6**
LNSP A-LNSP B Crosslink Interfaces	6.1	6.2	6.2
LNSP A-LNSP B DWE Interfaces	6.2	6.3	6.3
LNSP A-LNSP B Terrestrial Interfaces	6.3	6.4	6.4
LNSP A-LNSP B Network Layer Interfaces	6.4	N/A	N/A
References and Appendices	**7**	**7**	**7**
Acronyms	Appendix A	Appendix A	Appendix B
Signal Interface Descriptions	Appendix B	Appendix B	Appendix C Detailed Signal Definitions
LNSP-User Proximity Interfaces	B.i	B.i	4.2
Single Access LNSP-User Proximity Interfaces	B.i.i	B.i.i	N/A
Spread Spectrum LNSP-User Proximity Interfaces	B.i.ii	B.i.ii	N/A
LNSP – User DWE Interfaces	B.ii	B.ii	N/A
LNSP-User Contingency Interfaces	B.iii	B.iii	N/A
Interfaces Expected in LunaNet 1.0	B.iv	N/A	N/A
PNT Service to Link Mapping	Appendix C	Appendix C Navigation Parameters	N/A
Section Mapping Between LNIS v4 and v5	Appendix D	N/A	N/A
Removed/relocated from LNIS v4, LNIS v5 Draft			
Pseudo-Range and Timing Reference	Removed	3.2.1.2	3.2.1.2
Time-Transfer Reference	Removed. Supported by LANS/AFS	3.2.1.3	3.2.1.3
Pseudo-Range Measurement	Removed	3.2.3.2	3.2.3.2
Two-way transponder	Removed	3.2.5	3.2.5

Section Title	LNIS v5 Final	LNIS v5 Draft	LNIS v4
Map Dissemination	Removed	3.2.6.6	3.2.6.6
Conjunction Data	Removed	3.2.6.7	3.2.6.7
Location Service	Removed	3.2.7	3.2.7
Lunar Search and Rescue Services	Removed	3.4.1	3.3.1
Space Weather Alerting Services	Removed	3.4.2	3.3.2
Science Services	Removed	3.5	3.4
Single Access Links	Removed	3.6.3	N/A
Spread Spectrum Links	Removed	3.6.4	3.5.2
Link Establishment	Incorporated into Sec 3.5 and 4.1.	3.6.5	N/A
Service Combined Capabilities and Inter-Relationships	Removed	3.7	N/A
LNSP-User Lunar Surface Interfaces	Removed	4.1	4.1
LNSP A-LNSP B Lunar Surface Interfaces	Removed	6.1	6.1
LunaNet Interoperability Specification Phase Allocations	Removed. LNIS version 5 is LunaNet 1.0 specific.	Removed	Appendix A
LunaNet Application Messages	Incorporated into 3.3	Appendix D	Appendix D

APPENDIX ZZ TABLE OF TBXS

Table ZZ-1 below lists specific To Be Determined (TBD) and To Be Reviewed (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, parent section number, and number of the particular unresolved item. For example, "LNIS-TBD-6004" can be interpreted 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 struck through (~~LNIS-TBD-6004~~) in this table TBD. Items that are not part of LunaNet 1.0 will appear as struck-through text, with a description stating the item is "Not a LunaNet 1.0 item". 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.

Table ZZ-1: Table of TBXs

Designation	Section	Title	Description
~~LNIS-TBD-3001~~	~~3.1.2 /Table 4: Bundle Protocol Service Interfaces~~	~~Bundle Protocol Specification via TCP~~	~~Applicable document needed for Bundles / TCPCL. Bundles are forwarded via TCP convergence layer adapter over TCP/IP.~~ Resolved, added [AD19] CCSDS 734.2-P-1.1.
~~LNIS-TBD-3002~~	~~3.1.2 /Table 4: Bundle Protocol Service Interfaces~~	~~Bundle Protocol Specification via UDP~~	~~Applicable document needed for Bundles / UDPCL - Bundles are forwarded via UDP convergence layer adapter over UDP/IP.~~ Resolved, added [AD19] CCSDS 734.2-P-1.1.
LNIS-TBD-3003 (incorporating LNIS-TBD-3004, LNIS-TBD-3005, and LNIS4-TBD-3006)	3.3 Messaging Services	Messaging Services Definitions	Messaging Services specifications will be addressed with a combination of [AD3] {LNIS-TBD-AD0003} and [[AD6]{LNIS-TBD-AD0006}.

Designation	Section	Title	Description
~~LNIS-TBD-3007~~	~~3.2.1.2 Pseudorange and Timing Reference~~	~~Pseudo Noise Codes for Pseudorange Measurements~~	~~Pseudo-noise (PN) codes as identified in [AD13] 414.1-B-2 and [AD14] 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.~~ Not a LunaNet 1.0 item other than time-transfer via LANS/AFS.
~~LNIS-TBD-3008~~	~~3.2.1.3 Time-Transfer Reference~~	~~Time-Transfer Reference Method~~	~~A standardized method (TBD) for a LunaNet node to provide a time reference will be implemented to allow users to have accurate time.~~ Not a LunaNet 1.0 item other than time-transfer via LANS/AFS.
~~LNIS-TBD-3009~~	~~3.2.2.3 Range Measurement~~	~~Frame Ranging Specification~~	~~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.~~ Not a LunaNet 1.0 item.
~~LNIS-TBD-3010~~	~~3.2.2.3.1 Non-Regenerative Range Transponder~~	~~LNSP Transponding Bandwidth for Ranging Signals~~	~~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.~~ Not LunaNet 1.0 item.
~~LNIS-TBD-3011~~	~~3.2.3.1 Lunar Reference Frame~~	~~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 LNSPs or users. The lunar reference frame is described in detail in [AD5].~~ Closed this TBD and transferred to [AD5] and the associated {LNIS-TBD-AD0005}

Designation	Section	Title	Description
~~LNIS-TBD-3012~~	~~3.2.3.2 LunaNet Reference Time~~	~~LunaNet Reference Time~~	~~The use of a common LunaNet reference time across LNSP infrastructure elements is required to enable synchronization of services and time in the lunar domain. This common LunaNet reference time is described in detail in [AD5].~~ Closed this TBD and transferred to [AD5] and the associated {LNIS-TBD-AD0005}
~~LNIS-TBD-3013-1~~	~~[LNIS v4] 3.4.1 Lunar Search and Rescue (LunaSAR) Services~~	~~Lunar Search and Rescue Spectrum Allocation~~	~~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.~~ Not a LunaNet 1.0 item.
~~LNIS-TBD-3013-2~~	~~3.4.2 Space Weather Alerting Services~~	~~Space Weather Alert Message Definitions~~	~~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.~~ Not a LunaNet 1.0 item
LNIS-TBD-3014	3.5.2 User Initiated Services	User Initiated Service Options	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 3.5.2 and are still being determined.
~~LNIS-TBD-3015~~	~~3.5 Link Establishment~~	~~Link Establishment Standards~~	~~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.~~ Closed this TBD and transferred to [AD1 Vol-B] and the associated {LNIS-TBD-AD0001VB}
~~LNIS-TBD-4001~~	~~4. LunaNet Service Provider to User Interfaces~~	~~Optical Link Interface Standards~~	~~Standards for optical link interfaces are TBD.~~ Not a LunaNet 1.0 item

Designation	Section	Title	Description
~~LNIS-TBD-4002~~	~~LNIS v4 4.1 LNSP-User Lunar Surface Interfaces~~	~~Wireless Network 3GPP Specifications~~	~~LS3 - Short-to-medium range wireless network with mobility and roaming utilizing 3GPP rel. 16 (and higher) (LTE and 5G TBD).~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4003~~	~~LNIS v4 4.1 LNSP-User Lunar Surface Interfaces~~	~~LS3 Wireless Frequency Range~~	~~Target Frequency Range is TBD for LS3, Short-to-medium range wireless network with mobility and roaming.~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4004~~	~~Appendix B /Table B-23 PFS2 - Proximity Forward S-band Medium Rate w/ Ranging~~	~~PFS2 Frequency Assignments~~	~~Proximity Forward S-band Medium Rate w/ Ranging (PFS2) 2025-2110 MHz - Fixed frequency assignments TBD.~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4005~~	~~4.1/~~ Table ~~: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-23 PFS2 - Proximity Forward S-band Medium Rate w/ Ranging~~	~~PFS2 Coded Symbol Rate and Chip Rate~~	~~Proximity Forward S-band Medium Rate w/ Ranging (PFS2) 2025-2110 MHz - Coded Symbol & Chip Rates TBD.~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4006~~	~~Appendix B / Table B-24: PRS2 - Proximity Return S-Band Spread Spectrum~~	~~PRS2 Frequency Assignments~~	~~Proximity Return S-Band CDMA Return (PRS2) 2200-2290 MHz - Fixed frequency assignments TBD.~~ Not a LunaNet 1.0 item

Designation	Section	Title	Description
~~LNIS-TBD-4007~~	~~4.1/~~ Table ~~: LNSP User Proximity Interfaces Spread Spectrum, Appendix B / Table B-24: PRS2 – Proximity Return S-Band Spread Spectrum~~	~~PRS2 Coded Symbol Rate and Chip Rate~~	~~Proximity Return S-Band CDMA Return (PRS2) 2200-2290 MHz – Coded Symbol & Chip Rates TBD.~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4008~~	~~4.1/~~ Table ~~: LNSP User Proximity Interfaces Spread Spectrum, Appendix B / Table B-26: PRS5 – Proximity Return S-Band Multiple Access Return (MAR)~~	~~PRS5 Frequency Assignments~~	~~Proximity Return S-Band CDMA Return (PRS5) 2200-2290 MHz~~ ~~Fixed frequency assignments TBD.~~ Not a LunaNet 1.0 item.

Designation	Section	Title	Description
~~LNIS-TBD-4009~~	~~4.1/~~ Table ~~: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-26: PRS5 – Proximity Return S-Band Multiple Access Return (MAR)~~	~~PRS5 Coded Symbol Rate and Chip Rate~~	~~Proximity Return S-Band CDMA Return (PRS5) 2200-2290 MHz~~ ~~Coded Symbol & Chip Rates TBD.~~ Not a LunaNet 1.0 item.
~~LNIS-TBD-4010~~	~~4.1 / Table 7: LNSP-User Proximity Interfaces Single-Access, Appendix B / Table B-13: PFK1 – Proximity Forward K-band Data Only~~	~~PFK1 Coded Symbol Rate~~	~~Proximity Forward K-band Data Only (PFK1) 23.15-23.55 GHz~~ ~~1 Msps ≤ Rs ≤ TBD~~ ~~See Appendix B. II Note [15]~~ Closed this TBD and transferred to {LNIS-TBR-4013 } with a value of 2.048 Msps
~~LNIS-TBD-4011~~	~~4.1 /Table : LNSP-User Proximity Interfaces Single-Access, Appendix B / Table B-14: PFK2 – Proximity Forward K-band Variable Coding and Modulation~~	~~PFK2 Coded Symbol Rate~~	~~Proximity Forward K-band Variable Coding and Modulation (PFK2) 23.15-23.55 GHz~~ ~~1 Msps ≤ Rs ≤ TBD Msps~~ ~~See Appendix B B.II Note [15]~~ Not a LunaNet 1.0 item.

Designation	Section	Title	Description
LNIS-TBD-4012	Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B /Table B-15: PFK3-O - Proximity Forward K-band (OQPSK) High-Rate Data Only: PFK3-O – Proximity Forward K-band High-Rate Data Only	PFK3-O Coded Symbol Rate	Proximity Forward K-band High-Rate Data Only (PFK3-O) 23.15-23.55 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B B.II Note [15] Inserted {LNIS-TBD-4027 } for PKF3-G
LNIS-TBD-4013	Table 7: LNSP-User Proximity Interfaces Single Access: LNSP-User Proximity Interfaces Single Access, Table B-17: PFK4 - Proximity Forward K-band High-Rate Data w/ Ranging: PFK4 – Proximity Forward K-band High-Rate Data w/ Ranging	PFK4 Coded Symbol Rate	Proximity Forward K-band High-Rate Data w/ Ranging (PFK4) 23.15-23.55 GHz 1.5 Msps ≤ Rs ≤ TBD Msps See Appendix B B.II Note [15]

Designation	Section	Title	Description
~~LNIS-TBD-4014~~	~~4.1 / Table 7: LNSP-User Proximity Interfaces Single-Access, Appendix B /Table B-18: PRK1 – Proximity Return K-band Data Only~~	~~PRK1 Coded Symbol Rate~~	~~Proximity Return K-band Data Only (PRK1) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B I.I Note [15]~~ Closed this TBD and transferred to{LNIS-TBR-4014} with a value of 2.048 Msps
~~LNIS-TBD-4015~~	~~4.1 / Table 7: LNSP-User Proximity Interfaces Single-Access: LNSP-User Proximity Interfaces Single-Access, Appendix B / Table B-19: PRK2 – Proximity Return K-band Variable Coding and Modulation~~	~~PRK2 Coded Symbol Rate~~	~~Proximity Return K-band Variable Coding and Modulation (PRK2) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps~~ ~~See Appendix B B.II Note [15]~~ Not a LunaNet 1.0 item.
LNIS-TBD-4016	Table 7: LNSP-User Proximity Interfaces Single Access:, Table B-20: PRK3-O - Proximity Return K-band (OQPSK) High-Rate Data Only	PRK3-O Coded Symbol Rate	Proximity Return K-band High-Rate Data Only (PRK3-O) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps See Appendix B B.II Note [15] Applies to PRK3-O. Inserted {LNIS-TBD-4029} for PRK3-G

Designation	Section	Title	Description
LNIS-TBD-4017	Table 7: LNSP-User Proximity Interfaces Single Access, Table B-22PRK4 – Proximity Return K-band High-Rate Data w/ Ranging	PRK4 Coded Symbol Rate	Proximity Return K-band Data w/ Ranging (PRK4) 27.0-27.5 GHz 1.5 Msps ≤ Rs ≤ TBD Msps See Appendix B B.II Note [15]
~~LNIS4-TBD-4018~~	~~[LNIS V4] 4.2 / Table 9 – Coding and Framing of Proximity Signals~~	~~PFS/PRS 1e Coding~~	~~PFS/PRS 1e coding is TBD~~ Resolved, see Table B-6: PFS1e – Proximity Forward S-Band High Rate w/ Ranging, Table B-12: 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 Coded Symbol Rate~~	~~PFS/PRS 1e frequency and rate is TBD~~ Resolved, see Signal Interface Description Table B-6: PFS1e - Proximity Forward S-Band High Rate w/ Ranging, Table B-12: PRS1e - Proximity Return S-Band High Rate w/ Ranging
~~LNIS-TBD-4020~~	~~Appendix B/ Table B-26: PRS5 – Proximity Return S-Band Multiple Access Return (MAR)~~	~~PRS5 Coding and Framing~~	~~PRS5 Coding and Framing is TBD.~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4021~~	~~4.2/ Table 9: LNSP-User DWE signal interfaces, Appendix B / Table B-35: KU1 – K-band Uplink High Rate Data Only~~	~~KU1 Coded Symbol Rate~~	~~K-band Uplink High Rate Data Only (KU1) Frequency Range~~ ~~& Coded Symbol Rate - 22.55-23.15 GHz 2 Msps ≤ Rs ≤ 50 Msps (Upper Limit TBR)~~ Closed this TBD and transferred to {LNIS-TBR-4015 }.

Designation	Section	Title	Description
~~LNIS-TBD-4022~~	~~4.2/ Table 9: LNSP-User DWE signal interfaces, Appendix B /Table B-36: KU2 – K-band Uplink High Data w/ Ranging~~	~~KU1 Coded Symbol Rate~~	~~K-band Uplink High Rate Data Only (KU2) Frequency Range~~ ~~& Coded Symbol Rate 22.55-23.15 GHz 2 Msps ≤ Rs ≤ 50 Msps (Upper Limit TBR)~~ Closed this TBD and transferred to to {LNIS-TBR-4016
~~LNIS-TBD-4023~~	~~4.2/ Table 9: LNSP-User DWE signal interfaces, Appendix B/ Table B-37: KD1 – K-band Downlink High Rate Data Only~~	~~KD1 Coded Symbol Rate~~	~~K-band Downlink High Rate Data Only (KD1) 25.5-27.0 GHz 2 Msps ≤ Rs ≤ 200 Msps [Upper Limit TBR], See Appendix B.ii Note [12]~~ Closed this TBD and transferred to {LNIS-TBD-AD0006}.
~~LNIS-TBD-4024~~	~~4.2/ Table 9: LNSP-User DWE signal interfaces, Appendix B/ Table B-38: KD2 – K-band Downlink High Data w/ Ranging~~	~~KD2 Coded Symbol Rate~~	~~K-band Downlink High Data w/ Ranging (KD2)25.5-27.0 GHz 2 Msps ≤ Rs ≤ 200 Msps (Upper Limit TBR) See Appendix B.ii Note [12]~~ Closed this TBD and transferred to {LNIS-TBD-AD0003}.
LNIS-TBD-4025	Appendix B/ Signal Interface Descriptions	Standards for some DWE Link Interfaces	Applicable document for some signals are TBD. Standards development is an ongoing effort. See Appendix B/B.II Note [12], B.IV Note [11] and B.V Note [7]
~~LNIS-TBD-4026~~	~~4.1 / Table 7: LNSP-User Proximity Interfaces Single-Access, Appendix B / Table B-14: PFK2 – Proximity Forward K-band Variable Coding and Modulation~~	~~PFK2 Coding and Framing~~	~~PFK2 – Proximity Forward K-band Variable Coding and Modulation~~ ~~Coding and Framing: {TBD}~~ Not a LunaNet 1.0 item

Designation	Section	Title	Description
LNIS-TBD-4027	Table 7: LNSP-User Proximity Interfaces Single Access, PFK1 - Proximity Forward K-band Data OnlyPFK3-G – Proximity Forward K-band High-Rate Data Only	PFK3-G Coded Symbol Rate	Proximity Forward K-band High-Rate Data Only (PFK3-G) 23.15-23.55 GHz 1 Msps ≤ Rs ≤ TBD Msps
~~LNIS-TBD-4028~~	~~4.1 / Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B / Table B-14: PRK2 – Proximity Return K-band Variable Coding and Modulation~~	~~PRK2 Coding and Framing~~	~~PRK2 – Proximity Return K-band Variable Coding and Modulation~~ ~~Coding and Framing: {TBD}~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4029~~	~~4.1 / Table : LNSP-User Proximity Interfaces Single Access, Appendix B/ Table B-13: PRK3-G – Proximity Return K-band High-Rate Data Only~~	~~PRK3-G Coded Symbol Rate~~	~~Proximity Return K-band High-Rate Data Only (PRK3-G) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ TBD Msps~~ ~~See Appendix B B.II Note [15]~~

Designation	Section	Title	Description
~~LNIS-TBD-4030~~	~~4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-23 PFS2 – Proximity Forward S-band Medium Rate w/ Ranging~~	~~PFS2 Signal Definitions~~	~~PFS2 - Proximity Return S-Band Spread Spectrum~~ ~~Radiometric Ranging: Yes, details are {TBD}~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4031~~	~~4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-24: PRS2 – Proximity Return S-Band Spread Spectrum~~	~~PRS2 Signal Definitions~~	~~PRS2 – Proximity Return S-Band Spread Spectrum~~ ~~Radiometric Ranging: Yes, details are {TBD}~~ Not a LunaNet 1.0 item
~~LNIS-TBD-4032~~	~~4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-26: PRS5 – Proximity Return S-Band Spread Spectrum~~	~~PRS5 Polarization~~	~~PRS5 – Proximity Return S-Band Spread Spectrum~~ ~~Polarization: {TBD}~~ Not a LunaNet 1.0 item

Designation	Section	Title	Description
~~LNIS-TBD-4033~~	~~4.2/ Table 8: LNSP-User Proximity Interfaces Spread Spectrum, Appendix B / Table B-26: PRS5 – Proximity Return S-Band Spread Spectrum~~	~~PRS5 Signal Definitions~~	~~PRS5 – Proximity Return S-Band Spread Spectrum~~ ~~Radiometric Ranging: Yes, details are {TBD}~~ Not a LunaNet 1.0 item
~~LNIS-TBD-6001~~	~~6.1 / **Table** – LNSP–LNSP Crosslink Layer Interfaces~~	~~CFK1 Frequency Range~~	~~CFK1 Crosslink Forward Targeted Frequency Range is TBD~~ ~~23.15 – 23.55 GHz (TBD)~~ Resolved, see Table 13: LNSP–LNSP Crosslink Layer Interfaces
~~LNIS-TBD-6002~~	~~6.1 / **Table** – LNSP–LNSP Crosslink Layer Interfaces~~	~~CRK1 Frequency Range~~	~~CRK1 Crosslink Return Targeted Frequency Range is TBD~~ ~~27.00 – 27.50 GHz (TBD)~~ Resolved, see Table 13: LNSP–LNSP Crosslink Layer Interfaces
~~LNIS-TBD-6003~~	~~6.1 / **Table** – LNSP–LNSP Crosslink Layer Interfaces~~	~~CFK1 Applicable Documents~~	~~CFK1 Crosslink Forward Applicable Documents to be determined.~~ Resolved, see Table 13: LNSP–LNSP Crosslink Layer Interfaces
~~LNIS-TBD-6004~~	~~6.1 / **Table** – LNSP–LNSP Crosslink Layer Interfaces~~	~~CRK1 Applicable Documents~~	~~CRK1 Crosslink Return Applicable Documents to be determined.~~ Resolved, see Table 13: LNSP–LNSP Crosslink Layer Interfaces.
~~LNIS-TBD-AD0001~~	~~Applicable Documents~~	~~LunaNet Signal-In-Space Recommended Standard, Augmented Forward Signal~~	~~[AD1] – LunaNet and User Signal Structure Definition Document (TBD).~~ Resolved, [AD1 Vol-A] as released with LNIS V5.
LNIS-TBD-AD0001VB	Applicable Documents	LunaNet Signal-In-Space Recommended Standard, Point-to-Point Signals	[AD1 Vol-B] Point-to-Point Signals (Volume B)

Designation	Section	Title	Description
LNIS-TBD-AD0002	Applicable Documents	LunaNet Measurement Schema and Parameters Document	[AD2] LunaNet Measurement Schema and Parameters Document
LNIS-TBD-AD0003	Applicable Documents	LunaNet Detailed Message Definition Document	[AD3] LunaNet Detailed Message Definition Document
~~LNIS-TBD-AD0004~~	~~Applicable Documents~~	~~LunaNet Location Services for Users Document~~	~~[AD4] LunaNet Location Services for Users Document (TBD) other than time transfer via LANS/AFS~~. Placeholder. Not a LunaNet 1.0 item.
LNIS-TBD-AD0005	Applicable Documents	Lunar Reference System and LunaNet Reference Time System Standard	[AD5] Lunar Reference System and LunaNet Reference Time System Standard
LNIS-TBD-AD0006	Applicable Documents	LunaNet Data Services Document	~~[AD6] Reserved for Future Use.~~ Document number reassigned to [AD6] LunaNet Data Services Document.
~~LNIS-TBD-AD0007~~	~~Applicable Documents~~	~~LunaNet LunaSAR Definition Document~~	~~[AD7] LunaNet LunaSAR Definition Document (TBD).~~ Placeholder. Not a LunaNet 1.0 item.
LNIS-TBD-AD0008	Applicable Documents	LunaNet Interoperability Security Specifications	[AD8] LunaNet Interoperability Security Specifications
LNIS-TBD-AB0001	Services expected in LunaNet 1.0	Interfaces Identified in LunaNet 1.0	A TBD in Table B-47 indicates that availability of the interface for common providers is yet to be determined.
LNIS-TBD-AC0001	Appendix C 2-Way Doppler Measurements for K-Band services	2-Way Doppler Measurement Capabilities	Ability to add 2-Way Doppler measurement capabilities via PFK1/PRK1, PFK2/PRK2, PFK3/PRK3, PFK4/PRK4 is TBD.
LNIS-TBD-AC0002	Appendix C 2-Way Range Measurements for K-Band services	2-Way Range Measurement Capabilities	Ability to add 2-Way Range measurement capabilities via PFK4/PRK4 is TBD.

Designation	Section	Title	Description
~~LNIS-TBR-3001~~	~~[LNIS v4] 3.4.1 Lunar Search and Rescue (LunaSAR) Services~~	~~Interfaces for LunaSAR Alert Dissemination~~	~~LunaSAR's distress alert service is potentially received on PRS5 [TBR] and responded to over the AFS [TBR] links and are prioritized for rebroadcasting when received by the LNSP orbiting asset(s).~~ Not a LunaNet 1.0 item.
~~LNIS-TBR-4001~~	~~[LNIS v4] 4.1/Table 6 – LNSP User Lunar Surface - Surface Link Layer Service Interfaces~~	~~LS1 Frequency Range~~	~~For LS1 Short range wireless network Targeted Frequency Range 5.150–5.835 GHz (Lunar Near-side use only) (TBR) under study.~~ Not a LunaNet 1.0 item.
~~LNIS-TBR-4002~~	~~[LNIS V4] 4.2 / Table 8 - LNSP User Proximity Link Layer Service Interfaces]~~	~~PFS1b Ranging Chip Rate~~	~~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.
~~LNIS-TBR-4004~~	~~[LNIS V4] 4.2 / Table 8 - LNSP User Proximity Link Layer Service Interfaces~~	~~PFS1c Supplemental Reference for PN ranging~~	~~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. [AD1 Vol-B] to include ranging signal definitions.

Designation	Section	Title	Description
~~LNIS-TBR-4005~~	~~4.1/ Table 8: LNSP User Proximity Interfaces Spread Spectrum,~~ Appendix B~~/ Table B-23: PFS2 – Proximity Forward S-band Medium Rate w/ Ranging~~	~~PFS2 Spread Spectrum Modes~~	~~Proximity Forward S-band Medium Rate w/ Ranging (PFS2) SS-BPSK-CDMA (~3Mcps) or SS-UQPSK-TBR.~~ Not a LunaNet 1.0 Item.
~~LNIS-TBR-4006~~	~~[LNIS V4] 4.2 / Table 8 – LNSP User Proximity Link Layer Service Interfaces~~	PRS1b Ranging Chip Rate	~~Proximity Return S-Band Medium Rate w/ Ranging (PRS1b) Chip rate TBR~~ Resolved, see Appendix B Table B-8: 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~~	~~PRS1b Supplemental Reference for PN ranging~~	~~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-8: PRS1b - Proximity Return S-Band Medium Rate w/ Ranging [AD1 Vol-B] to include ranging signal definitions.
~~LNIS-TBR-4008~~	~~4.1/ Table 8: LNSP User Proximity Interfaces Spread Spectrum, Appendix B/ Table B-24: PRS2 – Proximity Return S-Band Spread Spectrum~~	~~PRS2 Spread Spectrum Modes~~	~~Proximity Return S-Band CDMA Return (PRS2) SQPN TBR.~~ Not a LunaNet 1.0 item.

Designation	Section	Title	Description
~~LNIS-TBR-4009~~	~~Appendix B/ Table B-20: PRS2 – Proximity Return S-Band Spread Spectrum~~	~~PRS2 Signal Parameter Flexibility~~	~~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].~~ Not a LunaNet 1.0 item.
~~LNIS-TBR-4010~~	~~4.1/ Table 8: LNSP User Proximity Interfaces Spread Spectrum~~, Appendix B~~/ Table B-26: PRS5 – Proximity Return S-Band Multiple Access Return (MAR)~~	~~PRS5 Spread Spectrum Modes~~	~~Proximity Return S-Band CDMA Return (PRS5) SS-BPSK-CDMA~~ ~~(~ 3Mcps) or SQPN (Appendix C) TBR~~. Not a LunaNet 1.0 item.
LNIS-TBR-4011	Appendix B/Table B- 2 PFS1b - Proximity Forward S-Band Medium Rate w/ Ranging, Table B-8: PRS1b Proximity Return S-Band Medium Rate w/ Ranging	PFS/PRS 1b Uncoded	PFS/PRS 1b uncoded is TBR

Designation	Section	Title	Description
LNIS-TBR-4012	Appendix B / Table B- 4 PFS1d-O – Proximity Forward S-Band High Rate Data Only, Table B-10: PRS1d-O – Proximity Return S-Band High Rate Data Only	PFS/PRS 1d-O Uncoded	PFS/PRS 1d-O uncoded is TBR Inserted {LNIS-TBD-AD0005} for PFS/PRS 1d-G
LNIS-TBR-4013	Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B/Table B-13: PFK1 - Proximity Forward K-band Data Only	PFK1 Coded Symbol Rate	Proximity Forward K-band Data Only (PFK1) 23.15-23.55 GHz 1 Msps ≤ Rs ≤ 2.048 Msps {TBR}
LNIS-TBR-4014	Table 7: LNSP-User Proximity Interfaces Single Access, Appendix B /Table B-18: PRK1 - Proximity Return K-band Data Only	PRK1 Coded Symbol Rate	Proximity Return K-band Data Only (PRK1) 27.0-27.5 GHz 1 Msps ≤ Rs ≤ 2.048 Msps {TBR}
LNIS-TBR-4015	4.2/ Table 9 LNSP-User DWE signal interfaces, Appendix B Table B-35: KU1 - K-band Uplink High Rate Data Only	KU1 Coded Symbol Rate	K-band Uplink High Rate Data Only (KU1) Frequency Range & Coded Symbol Rate - 22.55-23.15 GHz 2 Msps ≤ Rs ≤ 50 Msps {Upper Limit TBR}

Designation	Section	Title	Description
LNIS-TBR-4016	4.2/ Table 9: LNSP-User DWE signal interfaces, Appendix B / Table B-36: KU2 - K-band Uplink High Data w/ Ranging	KU2 Coded Symbol Rate	K-band Uplink High Rate Data Only (KU2) Frequency Range & Coded Symbol Rate 22.55-23.15 GHz 2 Msps ≤ Rs ≤ 50 Msps {Upper Limit TBR}
LNIS-TBR-4017	4.2/ Table 9 LNSP-User DWE signal interfaces, Appendix B/ Table B-37: KD1- K-band Downlink High Rate Data Only	KD1 Coded Symbol Rate	K-band Downlink High Rate Data Only (KD1) 25.5-27.0 GHz 2 Msps ≤ Rs ≤ 200 Msps [Upper Limit TBR], See Appendix B B.V Note [15]
LNIS-TBR-4018	4.2/ Table 9: LNSP-User DWE signal interfaces, Appendix B/ Table B-38: KD2 - K-band Downlink High Data w/ Ranging	KD2 Coded Symbol Rate	K-band Downlink High Data w/ Ranging (KD2)25.5-27.0 GHz 2 Msps ≤ Rs ≤ 200 Msps {Upper Limit TBR} See Appendix B B.V Note [12]
LNIS-TBR-4019	Appendix B/ PFS1d-G – Proximity Forward S-Band High Rate Data Only, Table B-11: PRS1d-G – Proximity Return S-Band High Rate Data Only	PFS/PRS 1d-G Uncoded	PFS/PRS 1d-G uncoded is TBR

Designation	Section	Title	Description
~~LNIS4-TBR-AP0001~~	~~Detailed Signal Definitions / Augmented Forward Signal Structure (AFS)~~	~~AFS Coded Symbol Rate~~	~~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).~~ Resolved, detailed signal definition AFS is included in [AD1 Vol-A]
LNIS-TBC-6001	6.1/ Table LNSP–LNSP Crosslink Layer Interfaces	CFK1/CRK1 Modulations	Crosslink Forward and Return Modulation Filtered OQPSK and GMSK {TBC} Confirm whether either modulation or just one of the stated modulations will be employed.