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International Communication System Interoperability Standards (ICSIS)

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Revision B – April 2024

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Approved by the Exploration Systems Development Mission Directorate in April 2024.

National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas
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REVISION AND HISTORY PAGE

REV.	DESCRIPTION	PUB. DATE
-	Baseline	March 2019
A	Revision A - Updated content to include HLS, and EVA surface comm - Updated modulation scheme on X-band Command and Telemetry link and S-band Lunar System link such that the modulation is consistent what is used with CCSDS PN ranging per CCSDS 401.0-B-30. - Added shorter LDPC codeword size for low data rates on X-band Command and Telemetry link and S-band Lunar System link to address latency issues at lower data rates -	September 2020

B	Revision B
	- Updated to broaden the perspective to Artemis-level as opposed to Gateway only
	- Updated to coordinate with Version 2 of the Draft LunaNet Interoperability Specification
	  - Added section for PNT
	  - Ensured compatibility for using LunaNet services
	- Added LunarSAR (Search and Rescue)
	- Added EVA Wireless standards
		April 2024

National Aeronautics and Space Administration
Johnson Space Center
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PREFACE

INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS (ICSIS)

This International Communication System Interoperability Standards (ICSIS) is to ensure end-to-end compatibility and interoperability between the elements of or in support to the Artemis missions, both in space and on Earth, enabling collaborative endeavors.

Configuration control of this document is the responsibility of the Moon to Mars (M2M) Control Board (M2MCB). The National Aeronautics and Space Administration (NASA) will maintain the International Communication System Interoperability Standard (ICSIS) under Exploration Systems Development Mission Directorate (ESDMD) M2M Program Office Configuration Management. Any revisions to this document will be approved by the M2MCB.

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1.0 INTRODUCTION

This International Communication System Interoperability Standards (ICSIS) is the result of a collaboration by the International Space Station (ISS) and Gateway membership to establish interoperable and compatible communications and navigation, where applicable, terminology, interfaces and techniques to facilitate collaborative endeavors of space exploration in cislunar and deep space environments. These standards are available for international and commercial partnerships.

Standards that are established and internationally recognized have been selected where possible to enable compatible solutions from a variety of providers. Increasing hardware/functional commonality among providers while decreasing unique configurations has the potential to reduce the traditional barriers in space exploration; overall mass and volume required to execute a mission. Standards reduce the scope and cost of the development effort, simplify interfaces and reduce operational complexity.

The information within this document represents a set of standards, which if accommodated in the system architecture, support greater efficiencies, promote cost savings, and increase the probability of mission success. These standards are not intended to specify design details needed for implementation nor do they dictate design features behind the interface. Interface specific requirements will be defined in interface control or requirement documents.

1.1 PURPOSE AND SCOPE

The purpose of the ICSIS document is to define the minimum set of functional, interface and performance standards necessary to support interoperable and compatible communications and position, navigation, and timing (PNT) between human exploration spacecrafts, lunar and earth ground infrastructure, and other space and surface systems. The ICSIS document also identifies a set of recommended functional and interface standards beyond the minimum set for interoperability. These recommended standards are identified for the RF interfaces where the minimum set of interoperability does not envelope the recommended standards for that RF interface.

The scope of the standard is for lunar and deep space human exploration missions and supporting infrastructure. The focus of this version of the document is on the Artemis lunar architecture to enable multiple international and commercial partners to build elements of the architecture that, if built to these minimum standards, can communicate with each other. The element is identified as either a provider or a user for each RF interface. The provider elements must meet all the minimum standards for that interface to be ICSIS compatible, but user elements may implement a select combination of the standards for that interface to be ICSIS compatible. The recommended standards identify interface definitions that exist for a set of provider elements to be used by the Artemis elements, but are not expected to be present for all provider elements. These elements of the lunar architecture may be human exploration spacecraft (both crewed and uncrewed), human exploration infrastrasture, Earth Ground Stations and Mission Control Centers, and LunaNet compatible lunar orbital

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relays[1]. The elements may be provided by NASA, International Partners, or commercial partners. These Artemis elements could be transiting in space, on the lunar surface, or orbiting the moon. Future Revisions of the document will incorporate any additional information or modifications needed for future deep space human exploration missions, such as missions to Mars.

The set of standards contained within the document do not specify the interfaces that are required for a particular program or project. They identify the standards that must be met for any interfaces chosen to be implemented by a project or program. Some interfaces may not be applicable to projects for early missions but may be phased in at a later time. The document accounts for all known RF interfaces that have been identified as planned capabilities. The document identifies potential interface and system combinations, but it is up to the programs to allocate the interfaces required for them to accomplish their mission. Once the programs allocate the interfaces, the interfaces specifications contained in this document should be used to ensure interoperability for those interfaces.

Interoperable, cross supportable, and compatible communications and navigation between space vehicles/systems, ground infrastructure, etc. is critical to the success of human exploration. It enables interchangeable use of National Aeronautics and Space Administration (NASA), International Partner, and commercial assets; decreases development and procurement costs; and reduces operational and training complexity. Some of the key challenges to a communication system and/or navigation system as humans venture further out into space are:

a. The ability to operate over different mission phases and be compatible with different ground, lunar surface, and space-to-space interfaces;
b. The need to handle spectrum constraints, longer latencies and disruptions;
c. An evolving, highly networked architecture and its implications (dissimilar systems putting data onto a single link, quality of service, security and network management, etc.);
d. System integration across multiple levels (infrastructure, multiple users, multiple control centers, etc.);
e. Going beyond GEO necessitates interfacing with multiple ground stations (NASA/International Partner and commercial), relays, as well as the associated different signal formats and messages;
f. Forward compatibility, extensibility, and scalability as additional capabilities are needed, enabling modifications/upgrades to different portions of the architecture.

A common set of standards and interfaces at the different layers of the protocol stack is essential to addressing the above challenges while addressing size, weight and power

[1] LunaNet encompasses networking and PNT techniques, standards, and an extensible framework to enable network capabilities and PNT services at the Moon. This framework will allow industry, academia, and space agencies to build and operate LunaNet nodes.

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constraints, and highly reliable operations. Components, systems, or vehicles delivered from multiple sources need to work together as an effective system to ensure success of actual missions. Such interoperability also enables partners to assist each other in emergency or contingency situations that can occur during exploration.

The architecture, standards, and protocols in the ICSIS document address both cislunar space as well as deep space missions. However, the focus of the document is on the cislunar space missions. The team is making every effort possible to ensure compatibility and extensibility of protocols and standards selected here to deep space missions. Future revisions of this document may include any modifications to the protocols and standards for deep space applicability. For example, the frequencies defined for the cislunar applications are per the near-Earth spectrum allocations. The frequencies for deep space excursions need to be added to be compliant with deep space spectrum allocations.

The communication and PNT standard makes use of existing Interagency Operations Advisory Group (IOAG) standard services and Consultative Committee on Space Data Systems (CCSDS) standards and protocols wherever possible. CCSDS is a multi-national forum for the development of interoperable and cross-supportable communications and data systems standards for spaceflight and has worked over the years to develop, reach agreement and implement standards and protocols for space vehicles. In cases where gaps are identified in CCSDS standards for a particular application or link, the ICSIS working group will work with the applicable CCSDS working group or other relevant standards development organization to standardize a commercial/industry standard or develop a new standard as appropriate. Appendix G has a list of applicable CCSDS standards in work and their scheduled completion dates.

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

Any proposed changes to this standard by the participating partners of this agreement shall be brought forward to the ICSIS committee for review.

Configuration control of this document is the responsibility of the Moon to Mars (M2M) Control Board (M2MCB). NASA will maintain configuration control of the ICSIS under M2M Program Office Configuration Management. Any revisions to this document will be approved by the M2MCB.

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2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, or other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

ANSI S3.2 (May 2009)	Method For Measuring the Intelligibility of Speech Over Communication Systems
Bluetooth Version 4.2	Bluetooth Classic and Bluetooth Low Energy (BLE), Dec. 2014
CCSDS 131.0-B-3	TM Synchronization and Channel Coding
CCSDS 133.1-B-2	Encapsulation Service
CCSDS 141.0-B-1	Optical Communications Physical Layer, Red Book
CCSDS 141.1-R-1-v10	Optical Communications Coding and Synchronization, Red Book
CCSDS 352.0-B-1	CCSDS Cryptographic Algorithms
CCSDS 355.0-B-1	Space Data Link Security Protocol
CCSDS 355.1-B-1	Space Data Link Security (SDLS) Extended Procedures
CCSDS 401.0-B-30	Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft
CCSDS 414.1-B-2	Pseudo-Noise (PN) Ranging Systems
CCSDS 415.1-B-1	Data Transmission and PN Ranging for 2 GHz CDMA Link via Data Relay Satellite
CCSDS 503.0-B-2	Tracking Data Message
CCSDS 702.1-B-1	IP Over CCSDS Space Links
CCSDS 702.1-B-1 Cor.1	IP Over CCSDS Space Links, Technical Corrigendum 1 to CCSDS 702.1-B-1
CCSDS 727.0-B-4	CCSDS File Delivery Protocol (CFDP)

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CCSDS 732.0-B-3	AOS Space Data Link Protocol
CCSDS 732.1-B-1	Unified Space Data Link Protocol, Blue Book, October, 2018
CCSDS 734.1-B-1	Licklider Transmission Protocol (LTP) for CCSDS
CCSDS 734.2-B-1	CCSDS Bundle Protocol Specification
CCSDS 735.1-B-1	Asynchronous Message Service
CCSDS 766.1-B-2	Digital Motion Imagery
CCSDS 766.2-B-1	Voice and Audio Communications
CCSDS 881.0-M-1	Spacecraft Onboard Interface Services – RFID Based Inventory Management Systems
FIPS PUB 197	Advanced Encryption Standard (AES) (2001)
IEEE 802.11n, 2.4 GHZ IEEE 802.11ax, 2.4 GHZ IEEE 802.11n, 5.0 GHZ IEEE 802.11ac, 5.0 GHZ IEEE 802.11ax, 5.0 GHZ IEEE 802.11ah, 900 MHZ	IEEE Standard for Information technology – Telecommunications and information exchange between systems Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
ITU P.863	Perceptual objective listening quality prediction (March 2018)
NIST SP 800-38D	Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC (2007)
Rec. ITU-R RA.479-5	Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon
REC SFCG 32-2R3	Communication Frequency Allocations and Sharing in the Lunar Region
RFC 768	User Datagram Protocol (August, 1980)

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RFC 791	Internet Protocol (September, 1981)
RFC 793	Transmission Control Protocol (September, 1981)
RFC 6071	IP Security (IPSec) and Internet Key Exchange (IKE) Document Roadmap (February, 2011)
RFC 7242	Delay-Tolerant Networking TCP Convergence Layer Protocol (June, 2014)
RFC 8200	Internet Protocol, Version 6 (IPv6) Specification (July, 2017)

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.

No Number	IOAG Service Catalog #2
No Number	The Future Lunar Communications Architecture: Report of the Interagency Operations Advisory Group Lunar Communications Architecture Working Group, V1.2
No Number	LunaNet Interoperability Specification
450-SNUG	Space Network Users' Guide (SNUG)
453-NENUG	NEN Network Users Guide
CCSDS 354.0-B-1	Symmetric Key Management
CCSDS 506.0-M-1	Delta-Differential One Way Ranging (Delta-DOR) Operations
CCSDS 727.0-B-5	CCSDS File Delivery Protocol (CFDP)
CCSDS 732.1-B-1	Unified Space Data Link Protocol
CCSDS 876.0-R-3	Spacecraft Onboard Interface Services – XML Specification For Electronic Data Sheets (in work)
CCSDS 901.1-M-1	Space Communications Cross Support – Architecture Requirements Document
DSN 810-005	Telecommunications Link Design Handbook

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DSN 820-100	Deep Space Network Services Catalog
JSC 27528	Space-to-Space Communications System Detailed Design Document
NASA STD-2822	Still and Motion Imagery Metadata Standard
CCSDS 883.0-B-1	Spacecraft Onboard Interface Services – High Data Rate 3GPP and WI-FI Local Area Communications

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3.0 INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS

3.1 GENERAL

The goal of establishing standards and agreeing on assumptions is to maximize the interoperability of space vehicles, relays, and ground systems, etc. of future human spaceflight missions conducted as international partnerships. The ability of components, systems, or vehicles delivered from multiple sources to work together as an effective system is important to the success of actual missions. Such interoperability also enables partners, other agencies and commercial companies to assist each other in emergency or contingency situations that can occur during cislunar and deep space missions. Good collaboration can make technology development and system maturation more efficient, by sharing the lessons learned and failures that drive requirements. Development of standards-based systems can also drive the costs to manufacture space systems lower, increasing the commercial and economic development potential of space and enabling more entities to participate. Using standard assumptions can also make development more efficient by making tests conducted by one partner relevant and valid to multiple partners.

Establishing a set of communication and PNT standards and designing it into the architecture, vehicles and supporting infrastructure is essential to ensure interoperability between communication end points to transfer data across multiple boundaries, networked communications, PNT signals and messages among providers and recipients, and compatibility with partner assets (ground stations, relay satellites, etc.). The communication and PNT systems interface extends beyond the spacecraft's mold-line and an agreed to set of standards is the key to ensuring all parts of the interface "talk" with each other.

3.1.1 ENGINEERING UNITS OF MEASURE

All dimensions are in International System of Units (SI units) (metric).

This section clarifies nomenclature and units of measure as it pertains to space communication systems:

1. Near Earth Frequency Band (also known as Near Space Frequency Band) – Frequency bands used when space vehicle is within 2 million kilometers from Earth as allocated by International Telecommunication Union (ITU).
2. Deep Space Frequency Band – frequency bands used when space vehicle is beyond 2 million kilometers from Earth as allocated by ITU for space research use.
3. Bit numbering convention – the following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0'; the following bit is defined to be 'Bit 1' and so on up to 'Bit N-1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see Figure 3.1.1-1, Bit Numbering Convention).

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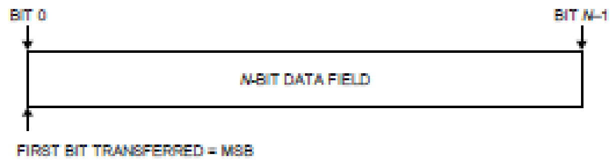

FIGURE 3.1.1-1 BIT NUMBERING CONVENTION

4. In accordance with standard data-communications practice, data fields are often grouped into 8- bit ‘words’ which conform to the above bit numbering convention - such an 8-bit word is called an ‘octet’. The numbering for octets within a data structure starts with 0.
5. By CCSDS convention, all ‘spare’ bits shall be permanently set to ‘0’.

3.2 LUNAR EXPLORATION SYSTEM COMM AND NAVIGATION INTERFACES

Table 3.2-1 below defines the terms used in this document to describe the communication and navigation systems and their roles. A system will be either a user or a provider of communication and PNT services.

The term “Lunar Exploration Systems” describes the multitude of Human Spaceflight systems, crewed or uncrewed, that will support Lunar Exploration.

Existing programs that consist of Gateway, Human Landing System (HLS), and Lunar Terrain Vehicle (LTV) are identified in the document as Lunar Exploration Systems. Other systems in early formulation are a pressurized rover, a lunar surface habitat, a European Large Logistic Lander, and a Mars transit vehicle as part of the Lunar Exploration architecture and could be provided by NASA or an International Partner. In this document, the communication and navigation interfaces between each other are identified in Table 3.2-2.

TABLE 3.2-1 DEFINITION OF TERMS

Term	Definition	Human Exploration System Examples	Other Examples
Lunar Exploration System (User or Provider depending on interface)	The multitude of Human Spaceflight systems, manned or unmanned, that will support Lunar Exploration	Gateway HLS LTV Pressurized Rover Habitat Logistic Landers	

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Term	Definition	Human Exploration System Examples	Other Examples
Ground (Provider)	The term used for the Earth side of the interface that performs the required function(s). This could be ground station(s) (examples: Deep Space Network (DSN), Near-Space Network (NSN), ESA tracking station network (Estrack), etc.) or it could be a combination of ground station(s) and control center(s) (Mission Operations Center (MOC), Mission Control Center (MCC), etc.). The ground station(s) used could be any of the NASA ground stations, an International Partner ground station, a commercial or other agency ground station or a combination of one or more available ground stations.		Ground Stations Mission Control Centers
Lunar Exploration Target Vehicle (Provider)	The role assumed by a spacecraft like Gateway that serves as a docking target vehicle for the Visiting Vehicles. For the Artemis III mission, one of HLS or Orion would be the "Lunar Exploration Target Vehicle" and the other would be the Visiting Vehicle.	Gateway HLS (Artemis III)	
Visiting Vehicle (User)	The role assumed by a spacecraft that docks to a Lunar Exploration Target Vehicle such as Gateway. For purposes of this document, the spacecraft is a visiting vehicle during rendezvous, proximity operations, docking, undocking, and docked operations. These could be Orion, Gateway's Logistics Module, and the Human Landing System (HLS).	Orion HLS GW Logistics Module	
EVA (User)	This category refers to Extravehicular activity (EVA) suits and equipment that directly supports or aids the astronauts to perform an EVA, like medical monitoring equipment within the suit.	EVA suits or EVA System	

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Term	Definition	Human Exploration System Examples	Other Examples
Orbiting Lunar Asset (Provider)	The role assumed by spacecraft or satellite in lunar orbit that communicates with a "Lunar System" which can include exchanging PNT signals and PNT messages. These could be LunaNet compatible satellites or Lunar Exploration Systems like Gateway. LunaNet compatible satellites and Gateway are able to relay data between Earth and Lunar Systems or between two Lunar Systems. There is also the case for Lunar Exploration Systems like Gateway where data is transferred between Gateway and the Lunar Systems and Gateway contains the communication link endpoints in addition the relay capability. These "Orbiting Lunar Assets" are communication and/or Position, Navigation, and Timing (PNT) service providers for Lunar Systems.	Gateway	LunaNet Compatible Relay
Lunar System (User)	The role assumed by a system that is on the lunar surface, in the vicinity of the moon, transiting from lunar orbit to lunar surface, or in lunar orbit. These could be landers like HLS, rovers like Lunar Terrain Vehicle (LTV), habitats, other payloads, CubeSats, science instruments, etc. The "Lunar System" is a user of the services provided by the "Orbiting Lunar Asset".	HLS LTV Pressurized Rover Habitat Logistic Landers	Payloads CubeSats Science Rovers
Lunar Search and Rescue (LunaSAR emitter / receiver) (Provider or User depending on interface)	Lunar Search and Rescue systems that allow emergency messaging to occur between Lunar Systems, Crew Systems, and Orbiting Lunar Assets.	TBD	TBD
LunaNet Lunar Augmented Navigation System (LANS) (Provider)	Multiple Orbiting Lunar Assets that together enable Position, Navigation, and Timing Services.		LunaNet Compatible Satellite System

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There are seven distinct Communication and Navigation interfaces that have been defined in this document as shown in Table 3.2-2.

One or more of the roles identified in Table 3.2-2 can be assigned to the same system. The role of a system determines the requirements and interfaces it must implement.

The green cells in Table 3.2-2 represent Communication and Navigation interfaces that are covered in this document.

TABLE 3.2-2 CURRENT STANDARDS CONTENT

System or role of a system (multiple roles can be assigned to the same system)	Interfaces						
	Earth Links	Rendezvous Links	EVA Comm Links	Wireless Networks	Lunar System Links	LunaSAR	LANS
Lunar Exploration System	USER		USER	PROVIDER			USER
Ground	PROVIDER						
Lunar Exploration Target Vehicle		PROVIDER					
Visiting Vehicle		USER					
EVA			USER	USER			
Orbiting Lunar Asset					PROVIDER		
Lunar System					USER		
Lunar Search and Rescue						USER / PROVIDER	USER
LunaNet LANS							PROVIDER

The following sections describe the communication and navigation interfaces and provide the set of recommended and minimum standards to be used to provide interoperability and compatibility.

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The standards defined in the following sections are for Lunar Exploration Systems used for human exploration missions and their interfaces. The current focus is on cislunar space missions. Extensibility to other deep space human missions has also been considered while selecting standards and protocols. Potential future updates to the document would incorporate additional information or modifications for deep space human exploration missions if needed. In the current ConOps, Gateway is a Lunar Exploration System in orbit providing a platform for conducting research and experiments, crew habitation, staging other missions, etc. remaining in orbit for a minimum of 15 years. Multiple visiting vehicles (lunar lander, Logistics Module, and Orion) arrive with visiting vehicle role and perform rendezvous, proximity operations and docking (RPOD) with the Lunar Exploration Target Vehicle (Gateway). The two spacecraft can communicate and perform radiometric tracking over the Rendezvous link with the rendezvous operation starting at a range of about 400 km. The lunar lander undocks from the orbiting Gateway to transit to the Lunar Surface. The lunar lander can communicate with Gateway over the Rendezvous link during undocking and within the Rendezvous link range. During lunar lander transit to the lunar surface, from the lunar surface, and on the lunar surface, the lander has the role of Lunar System as viewed by the orbiting Lunar assets (LunaNet satellites and Gateway) and the spacecraft communicate over the Lunar System links. Therefore, based on the mission phase, the spacecraft plays different roles and would communicate using the appropriate interfaces. Lunar surface systems will include habitats, rovers, EVA suits, landers containing experiments, surface infrastructure such as power systems that will communicate and navigate relative to each other using the appropriate interfaces and capabilities.

The communication standards and protocols provide the recommended and minimum capability required to support interoperable communications across these interfaces at the physical, space data link, and network layers plus at some select application layers. This allows for ground and flight elements of the Lunar Exploration architecture to be able to communicate with each other during nominal or contingency operations. It is expected that LunaNet Satellites will be able to forward data between RF interfaces using either network layer routing or link layer switching. Gateway is able to support link layer switching for AOS virtual channels that contain space packets, but virtual channels containing DTN bundles or IP Packets will use network layer routing.

A set of recommended standards for RF interfaces to support navigation are identified. This set of standards and protocols is not sufficient for fully interoperable Position, Navigation, and Timing (PNT) Services. The set of PNT standards and protocols will be updated as the standards and protocols are matured within the LunaNet Interoperability Specification.

The recommended standards and protocols for the Ground and LunaNet compatible satellites are identified in this document, but this document is not levied on these systems. The standards supported by the Ground for the Lunar Exploration Missions have been identified as being present in DSN and planned in NSN. Some Earth Communication standards and protocols may not be within every partner or commercial ground station, but these were agreed to and considered satisfactory for Ground

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interoperability. The standards and protocols supported by LunaNet compatible satellites are identified within the LunaNet Interoperability Specification. There was collaboration between the LunaNet team and the ICSIS working group to have the ICSIS Lunar System Links and ICSIS Wi-Fi and 3GPP standards and protocols supported within the LunaNet Interoperability Specification. This alignment allows ICSIS to specify the LunaNet compatible services as being interoperable with Lunar Systems that are compliant with the Lunar System Link standards and protocols. ICSIS and the LunaNet Interoperability Specification have some overlap in their specified standards, but ICSIS identifies a subset of the LunaNet standards and protocols for interfaces that are in scope for both interoperability specifications. There also exist interfaces covered in ICSIS that aren't within LunaNet (EVA, Rendezvous) and interfaces in LunaNet that aren't in ICSIS (Network Cross Support Interfaces).

The ICSIS standards and protocols define the recommended and minimum set of standards for each interface for interoperable communications. If the Lunar Exploration System is a service provider like Gateway for the Visiting Vehicle and Lunar System links, then the system needs to:

- Define the interfaces it agrees to provide;
- For each interface, implement the minimum set of standards.
- For each interface, implement any desired recommended standards

If the Lunar Exploration System is a user, then it needs to:

- Select interfaces it needs to make use of to satisfy the mission needs;
- For each interface, implement the minimum set of standards to ensure interoperability.
- For each interface, implement desired recommended standards to maximize interoperability with increased capabilities
- For each interface, user can define capabilities not identified within ICSIS, but these would not have any assumption of interoperability

For example, a Lunar Exploration System is interoperable as per ICSIS on the high data rate Radio Frequency (RF) link with Earth interface only if it implements the set (or a subset) of minimum standards given in Section 3.2.2.2.2.1. In addition to these, the system can implement additional capabilities and interfaces for its unique needs.

This document defines all the set of recommended and minimum standards as requirements for each interface, thus making it "stand alone".

3.2.1 DESCRIPTION OF ARTEMIS ELEMENT COMMUNICATION, NAVIGATION, AND TIMING INTERFACES

The Lunar Exploration Systems may include the following RF interfaces depending on the roles it needs to cover:

- Earth Link: Telemetry, Tracking, and Command (TTC) – DTE Link - A long-range, low data rate interface with Earth Systems (direct-to-Earth or via relay) that enables

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a standard, reliable path for basic command and telemetry operations and to make radiometric measurements. Standards are also provided for contingency communication operations which will be performed over this interface to recover from spacecraft emergencies and contingencies;

- Earth Link: High Rate – DTE Link - A long range, high data rate, RF and Optical interfaces with Earth Systems (direct-to-Earth or via relay) to exchange user and scientific data that require a higher-bandwidth capability; Future capabilities expectated for radiometric tracking on high rate RF links and data exchange and optimetric tracking on high rate Optical links.
- Rendezvous Link - A short range, space-to-space interface with Visiting Vehicle (VV) Systems that enables data exchange and radiometric tracking during rendezvous and proximity operations between the Lunar Exploration Target Vehicle and a VV;
- EVA Communication Link - An short range interface that enables core communications between Extravehicular activity (EVA) systems: EVA to EVA as well as EVA to Lunar Exploration System;
- Wireless Networks - Internal and external wireless local area networked communications enabling high rate communications and radiometrics (for 3GPP links) between the Intra-vehicular activity (IVA), EVA, cameras, crew laptops and devices, sensors, free flying robotic cameras, payloads, etc.;
- Lunar System Links - A mid-range interface between Orbiting Lunar Assets and Lunar Systems that enables data exchange and radiometric measurements between the Orbiting Lunar Asset and the Lunar System on the lunar surface, orbiting the moon or in the vicinity of the moon.
- LunaSAR – A set of short range and/or mid range interfaces between LunaSAR transmitters and receivers that enable emergency messaging to occur between Lunar Systems on the Lunar Surface, EVA Systems, and Orbiting Lunar Assets.
- Lunar Navigation Satellite Systems – A mid-range interface of multiple Orbiting Lunar Assets to Lunar Exploration Systems (and other non-human exploration Lunar Systems) to enable Position, Navigation, and Timing Services.

The standards for audio and video communications between the Lunar Exploration Systems, EVA Systems, and Ground as well as within Lunar Exploration Systems are defined in this document. The data bandwidth of the communication links is dynamically allocated based on the scheduled data to be transmitted, quality of service, etc. Currently there are no plans to have pre-allocated bandwidth for audio, video, commands of any other specific data types. Priority and quality of service of the data transmission is based on the data to be transmitted and mission phases. Voice communication with the crew or between crew members is high priority especially in critical situations and must not be interrupted by video or lower priority data transmission. There are hardline interfaces between the attached elements to allow data transfer (including audio and video) between docked Visiting Vehicles and this hardline interface is further defined in the International Avionics System Interoperability Standards (IASIS), and not covered in this document.

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The Lunar Exploration System RF Interfaces are shown in Figure 3.2.1-1, Lunar Exploration Interfaces. As noted before, the Lunar Exploration System – Earth link could be a direct link or via a relay. Similarly, the Orbiting Lunar Asset - Lunar Systems link could be a direct link or via a relay.

The detailed breakdown of data transferred between Lunar Exploration System and Earth and between Lunar Exploration Target Vehicle and a VV is given in Appendix D. Similar data would be transferred between the Lunar Exploration Systems in Lunar Orbit (Gateway) and Lunar systems, EVAs, payloads, etc. Functional data flow between the elements for a generic cislunar/planetary mission is given in Appendix E.

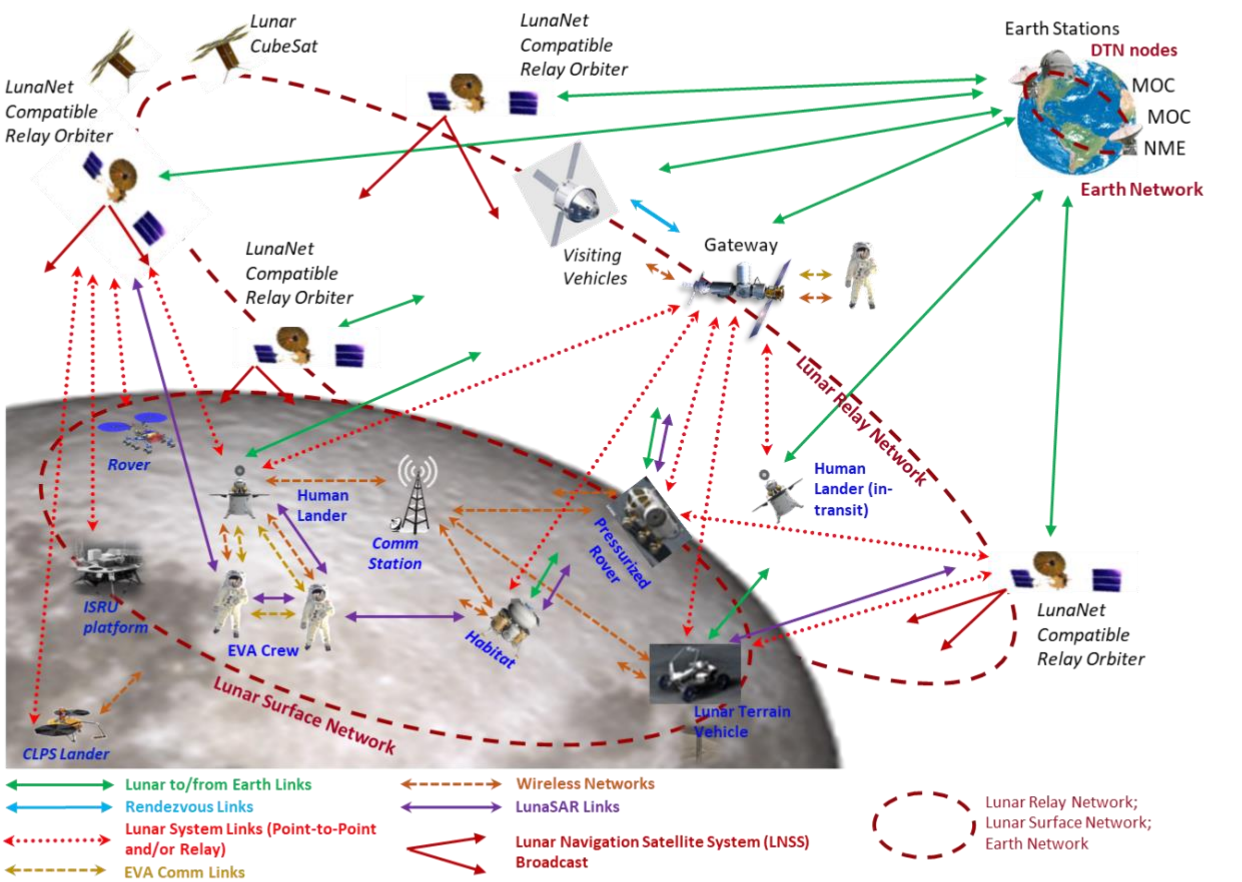

FIGURE 3.2.1-1 LUNAR EXPLORATION RF INTERFACES

3.2.2 INTERFACE STANDARDS

3.2.2.1 GENERAL

This section has communication interoperability requirements common to all Lunar Exploration System links.

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3.2.2.1.1 SPECTRUM

This section addresses the standards and requirements associated with the radio frequency spectrum allocations, constraints and regulations. The standards and requirements dealing with electromagnetic compatibility (EMC) and electromagnetic interference (EMI) will be covered in other requirements documents and not addressed here.

Comm-1: Lunar Exploration Systems shall comply with radio frequency selection as defined in REC SFCG 32-2R3, Communication Frequency Allocations and Sharing in the Lunar Region.

Comm-290: EVA Systems shall comply with radio frequency selection as defined in REC SFCG 32-2R3, Communication Frequency Allocations and Sharing in the Lunar Region.

Rationale: Compliance with the Space Frequency Coordination Group (SFCG) recommendation on frequency use for the lunar region.

Comm-2: Lunar Exploration Systems shall comply with radio frequency allocation and conditions of assignment for frequency spectrum usage approved by the ITU and respective International Partners' national spectrum usage regulations.

Comm-291: EVA Systems shall comply with radio frequency allocation and conditions of assignment for frequency spectrum usage approved by the ITU and respective International Partners' national spectrum usage regulations.

Rationale: Allocations of spectrum and constraints of its use is governed by each International Partners' national regulations. For example, there is a European Regulation for allocated frequency selection and spectrum use (European Radiocommunications Committee (ERC) Report 25) dictated by the Electronic Communications Committee (ECC) and European Conference of Postal and Telecommunications Administrations (CEPT) from Europe. Allocations of frequency spectrum for U.S. Government systems, including NASA, are managed by the National Telecommunications and Information Administration (NTIA). U.S. commercial companies' spectrum is regulated by the Federal Communications Commission (FCC).

Comm-241: Lunar Exploration Systems' RF systems shall be compatible with other Lunar Exploration Systems, EVA RF systems, and Visiting Vehicle RF systems.

Comm-292: EVA RF systems shall be compatible with other Lunar Exploration Systems, other EVA RF Systems, and Visiting Vehicle RF systems.

Rationale: This requirement ensures that the RF communications systems used by each element and visiting vehicles are compatible with each other. RF compatibility and interference analysis will be performed

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during frequency selection to ensure that the specific frequencies selected are compatible with each other.

3.2.2.1.2 AUDIO

The crew on-board a Lunar Exploration System, will use the Lunar Exploration System audio communications to communicate with each other and VV crew, communicate with EVA crew, for discussions with Ground, and for personal, private communications with family and medical personnel. The requirements given below are the minimum requirements needed to support interoperable audio communications.

Comm-3: The Lunar Exploration System shall comply with CCSDS 766.2-B-1, Voice and Audio Communications, for all voice and audio exchanges.

Comm-293: The EVA System shall comply with CCSDS 766.2-B-1, Voice and Audio Communications, for all voice and audio exchanges.

Rationale: Crew will need voice and audio communications with Earth, VVs, Lunar assets, EVAs, etc. and having interoperable communications between them is essential to save cost, complexity and size weight and power. This applies to all Orbiting Systems, Surface Systems, and EVA System that implement voice or audio systems to support the Lunar Exploration Missions.

Comm-4: The Lunar Exploration System audio system shall be tested in accordance with ANSI S3.2, Method for Measuring the Intelligibility of Speech Over Communication Systems, for subjective speech intelligibility.

Comm-294: The EVA System audio system shall be tested in accordance with ANSI S3.2, Method for Measuring the Intelligibility of Speech Over Communication Systems, for subjective speech intelligibility.

Rationale: Lunar Exploration System audio systems need to meet the intelligibility requirements to ensure that the audio and voice of different speakers over the system is comprehensible under different conditions. This applies to all Orbiting Systems, Surface Systems, and EVA Systems that implement voice or audio systems to support the Artemis Mission.

Comm-5: DELETED

3.2.2.1.3 VIDEO

A Lunar Exploration System's video will be sent across multiple links for the purposes of engineering, science and public awareness. The crew will also use the video interface for personal communications with family and medical personnel. To ensure interoperability over these multiple interfaces and display conditions, Lunar Exploration System's video formats, interfaces, encapsulation, and transmission protocols need to be consistent with CCSDS 766.1-B-2, Digital Motion Imagery, where practical

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depending on interoperability with avionics, human system interfaces, and other areas where video interoperates with other systems.

Comm-6: Lunar Exploration Systems shall comply with interface standards for compressed and non-compressed television signals specifically referenced in CCSDS 766.1-B-2, Digital Motion Imagery.

Comm-295: EVA Systems shall comply with interface standards for compressed and non-compressed television signals specifically referenced in CCSDS 766.1-B-2, Digital Motion Imagery.

Rationale: Lunar Exploration Systems are likely to have camera and video systems from multiple sources that need to be interoperable. The CCSDS standard has already been agreed upon by multiple agencies and references video industry standards.

Comm-7: Lunar Exploration Systems shall acquire and distribute multiple resolutions and frame rates consistent with CCSDS 766.1-B-2, Digital Motion Imagery.

Comm-296: EVA Systems shall acquire and distribute multiple resolutions and frame rates consistent with CCSDS 766.1-B-2, Digital Motion Imagery.

Rationale: Lunar Exploration System's video system will need to be scalable to support multiple operational scenarios where bandwidth is limited or communication links are limited. The CCSDS standard has already been agreed upon by multiple agencies and references multiple video resolutions and frame rates.

Comm-8: Lunar Exploration Systems shall provide compressed video signals with encapsulation and internet protocol transmission consistent with CCSDS 766.1-B-2, Digital Motion Imagery.

Comm-297: EVA Systems shall provide compressed video signals with encapsulation and internet protocol transmission consistent with CCSDS 766.1-B-2, Digital Motion Imagery.

Rationale: Uncompressed video far exceeds the bandwidth available between spacecraft and from spacecraft to ground via real-time communication links; therefore, video will need to be compressed. Compressed video will need to be encapsulated for routing between spacecraft elements and to the ground. The CCSDS standard has already been agreed upon by multiple agencies and references multiple options for compression, encapsulation, and transmission, including Disruption Tolerant Networking (DTN).

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Comm-9: Lunar Exploration Systems should **<TBD 3-7>** provide metadata with imagery consistent with the protocols outlined in NASA STD 2822, Still and Motion Imagery Metadata Standard, where practical depending on interoperability with other systems.

Comm-298: EVA Systems should **<TBD 3-7>** provide metadata with imagery consistent with the protocols outlined in NASA STD 2822, Still and Motion Imagery Metadata Standard, where practical depending on interoperability with other systems.

Rationale: Data such as timing, camera location, and azimuth will be critical for monitoring operations, health and status of spacecraft and crew. The NASA Standard for imagery metadata references specific fields of data from National Institute of Standards and Technology (NIST) standards. CCSDS is working on standard CCSDS 876.0-R-3, Spacecraft Onboard Interface Services – XML Specification for Electronic Data Sheets, which should cover metadata. Once this standard is completed, approved and agreed to implementation by the International Partners, the above requirement will be updated.

3.2.2.2 LUNAR EXPLORATION SYSTEM - EARTH COMMUNICATION LINKS

The subsections below contain the communication standards specific to the Lunar Exploration System to Earth Links. The Lunar Exploration System to Earth links are broken into the Telemetry, Tracking, and Command link, the High Rate Links (RF and Optical), and the Contingency Communications link. The standards selected for these links maximize interoperability and compatibility with the different ground networks/stations (including NASA, IPs, commercial, etc.) for data exchange and radiometrics (or optimetrics in the case of the optical links). These standards and protocols are consistent with the draft recommendations coming out of the IOAG Lunar Communications Architecture Working Group (LCAWG) study.

The communications link between Lunar Exploration System and Earth is used for sending:

1. Commands, configuration updates, guidance, navigation, and control (GN&C) state information, file uploads, audio, video, etc., from Earth to Lunar Exploration System;
2. Health and status data, engineering/science/payload data, file downloads, audio, video, etc. from Lunar Exploration System to Earth.

Detailed list of data transferred between Lunar Exploration Systems and Earth during crewed and un-crewed operations of a Lunar Exploration System is given in Appendix D.

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3.2.2.2.1 TELEMETRY, TRACKING, AND COMMAND COMMUNICATION LINKS

The Telemetry, Tracking, and Command link provides for the core communications to command and monitor Lunar Exploration System. It is also used to track the Lunar Exploration System from Earth using radiometric tracking. This communication link uses X-band for uplink and downlink.

The rationale for selecting X-band is:

A. Scalability to Mars and other deep space destinations;

B. Better power efficiency compared to S-band;

C. Ability to handle higher data rates than S-band (its spectrum allocation allows for higher data rates than S-band); the bandwidth allocation limitations on X-band is 10 megahertz (MHz) per user (data rate is dependent on the modulation and coding used);

D. Better trade with antenna size/gain;

E. Supports radiometric tracking;

F. Ground stations support both uplink and downlink (Ka-band uplink currently not supported by all NASA and partner Ground Stations);

G. Availability of space heritage, mature technology.

H. S-band links are increasingly degraded by radio frequency interference (RFI) from other spacecraft in the near-Earth regime.

The minimum standards for the Telemetry, Tracking, and Command link are summarized in Table 3.2.2.2-1, Minimum Standards for Telemetry, Tracking, and Command Link. The nominal data rates given below are based on sharing of the narrow X-band spectrum between different users/missions.

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TABLE 3.2.2.2-1 MINIMUM STANDARDS FOR TELEMETRY, TRACKING, AND COMMAND LINK SERVICE PROVIDERS[11]

Symbol Rates[1, 10, 12]	Modulation and Encoding[1, 10]	Ranging	Coding LDPC[4]	Space Data Link Protocol AOS[3], USLP[5]	Space Data link Security
X-band Forward Link (7190-7235 MHz)[6] (Earth to Lunar Exploration System)					
128 ksps ≤ symbol rate ≤ 10 Msps	Filtered OQPSK + NRZ-L	No	Code Rates ½, 4/5, 7/8, uncoded with following codeword size and ASM depending on mode selected: • 4096 octets plus 64 bit ASM (for rate ½) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the coding mode selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[8]
64 ksps ≤ symbol rate ≤ 5 Msps	Filtered BPSK + NRZ-L	No			
64 ksps < symbol rate < 1.024 Msps	PCM/PM/Bi-phase-L (modulation on residual carrier)	Yes[2]			
0.5 ksps ≤ symbol rate ≤ 64 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]	LDPC Code rate ½ with following codeword size and ASM: • 256 octets plus 64 bit ASM • Uncoded size: 128 octets plus a 32 bit ASM	• 128 octets (for LDPC rate ½ or uncoded)	
X-band Return Link (8450-8500 MHz)[6] (Lunar Exploration System to Earth)					
128ksps ≤ symbol rate ≤ 8 Msps[7]	Filtered OQPSK + NRZ-L	No	Code Rates ½, 4/5, 7/8, uncoded with following codeword size and ASM depending on mode selected: • 4096 octets plus 64 bit ASM (for rate ½) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • Uncoded size: 2048 octets plus a 32 bit ASM	Depending on the coding mode selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[8]
64 ksps ≤ symbol rate ≤ 4 Msps[7]	Filtered BPSK + NRZ-L	No			
64 ksps < symbol rate ≤ 1.024 Msps[7]	PCM/PM/Bi-phase-L (modulation on residual carrier)	Yes[2]			
0.1 ksps[9] ≤ symbol rate ≤ 64 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]	LDPC Code rate ½ with following codeword size and ASM: • 256 octets plus 64 bit ASM • Uncoded size: 128 octets plus a 32 bit ASM	• 128 octets (for LDPC rate ½ or uncoded)	

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter. **The symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation**
2. CCSDS PN Ranging, Non-regenerative. Ranging chip rate: ≤ 4 Mcps per CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems, Blue Book
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. The symbol rate on the downlink is limited to BPSK 4 Msps to better share the narrow X-band spectrum between different users/missions. Maximum symbol rates are consistent with the IOAG LCA recommendations. The LCAWG recommended Bi-phase-L and GMSK. Given that not all partner Ground stations currently implement GMSK, the ICSIS baseline is OQPSK instead of GMSK. Once all the partners implement GMSK on the infrastructure side, this will become a part of the interoperability standard. The maximum symbols rates for the specific modulation are adjusted accordingly. The PCM/PM/Bi-phase-L symbol rate is limited to 1.024 Msps based on analysis of the PN ranging performance, signal degradation, and bandwidth needs.
8. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
9. Lower limit based on ECSS (European Cooperation Space Standardization)/CCSDS. User symbol rates lower than 0.1 ksps can be supported on a case-by-case basis.
10. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (Future version 401.0 is expected to address higher PCM/PSK/PM symbol rates.)
11. Users of these services may select the capabilities required to implement the end-to-end interoperable link configurations needed for their mission to be ICSIS compliant.
12. Uncoded modes are only for contingencies and do not need to be supported over the full range of symbol rates.

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3.2.2.2.1.1 FREQUENCY

Comm-10: Lunar Exploration Systems shall use 8450-8500 MHz (X-band) frequency band to transmit signals to Ground (Earth) on the Telemetry, Tracking, and Command link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations. This applies to all Orbiting and Surface Lunar Exploration Systems that implement Direct to Earth links for command and telemetry. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-11: Ground shall use 8450-8500 MHz (X-band) frequency band to receive signals from Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-12: Lunar Exploration Systems shall use 7190-7235 MHz (X-band) frequency band to receive signals from Ground (Earth) on the Telemetry, Tracking, and Command link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations. This applies to all Orbiting and Surface Lunar Exploration Systems that implement Direct to Earth links for command and telemetry. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-13: Ground shall use 7190-7235 MHz (X-band) frequency band to transmit signals to Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-14: Deleted

3.2.2.2.1.2 MODULATION ON THE TELEMETRY, TRACKING, AND COMMAND LINK

The required standards for modulation on the Telemetry, Tracking, and Command link are summarized in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, and expanded in this section.

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Comm-15: Lunar Exploration Systems shall implement filtered Binary Phase Shift Keying (BPSK) and filtered Offset Quadrature Phase-Shift Keying (OQPSK) for symbol rates within the ranges defined in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2 to transmit and receive signals on the Telemetry, Tracking, and Command link.

Rationale: BPSK is selected because it is a common mode supported by a majority of ground stations. OQPSK is bandwidth efficient. Filtering is used to meet the spectral constraints. The symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation.

Comm-233: Ground shall implement filtered BPSK and filtered OQPSK for symbol rates within the ranges defined in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2 to transmit and receive signals on the Telemetry, Tracking, and Command link

Rationale: BPSK is selected because it is a common mode supported by a majority of ground stations. OQPSK is bandwidth efficient. Filtering is used to meet the spectral constraints. The symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation.

Note: OQPSK defined in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, is not listed as a choice for uplinks. However, in view of the symmetric property of the AOS space data link protocol, OQPSK can be used on the uplinks. The CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft standard is being updated to include this mode on the uplinks.

Comm-16: Lunar Exploration Systems shall implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rates within the ranges defined in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems-Part 1: Earth Stations and Spacecraft, Section 2 on the Telemetry, Tracking, and Command link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; it meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies. This mode supports CCSDS PN ranging.

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Comm-17: Ground shall implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rates within the ranges defined in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems-Part 1: Earth Stations and Spacecraft, Section 2 on the Telemetry, Tracking, and Command link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; it meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies. This mode supports CCSDS PN ranging.

Comm-18: Lunar Exploration Systems shall implement PCM/PSK/PM with modulation on sub-carrier for symbol rates within the ranges defined in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, and not exceeding sub-carrier frequency of 320kHz to transmit and receive signals, as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems-Part 1: Earth Stations and Spacecraft, Section 2 on the Telemetry, Tracking, and Command link.

Rationale: PCM/PM/PSK with modulation on sub-carrier provides interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; it meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies. This mode supports CCSDS PN ranging.

Comm-19: Ground shall implement PCM/PSK/PM with modulation on subcarrier for symbol rates within the ranges defined in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, and not exceeding sub-carrier frequency of 320kHz to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems-Part 1: Earth Stations and Spacecraft, Section 2 on the Telemetry, Tracking, and Command link.

Rationale: PCM/PSK/PM with modulation on subcarrier provides interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; it meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies. This mode supports CCSDS PN ranging.

3.2.2.2.1.3 CODING AND SYNCHRONIZATION ON THE TELEMETRY, TRACKING, AND COMMAND LINK

The required standards for coding and synchronization on the Telemetry, Tracking, and Command link are summarized in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, and expanded in this section.

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Comm-20: Lunar Exploration Systems shall be able to enable or disable forward error correction (FEC) to support contingency operations with Ground on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to be able to enable or disable FEC to support contingency and other operational scenarios. Uncoded modes are supported for lower range of symbol rates since they are used for contingency and are not used to specify or drive the performance of the Comm systems.

Comm-21: Ground shall be able to enable or disable FEC to support contingency operations with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to able to enable or disable FEC to support contingency and other operational scenarios. Uncoded modes are supported for lower range of symbol rates since they are used for contingency and are not used to specify or drive the performance of the Comm systems.

Comm-22: For symbol rates greater than 64 ksps, Lunar Exploration Systems shall use CCSDS Low Density Parity Codes, rate ½, rate 4/5, or rate 7/8 for encoding and decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: The bandwidth overhead and coding gain vary by the code selected. Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

Comm-23: For symbol rates greater than 64 ksps, Ground shall use CCSDS Low Density Parity Codes, rate ½, rate 4/5, and rate 7/8 for encoding and decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: The bandwidth overhead and coding gain vary by the code selected. Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

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Comm-24: For symbol rates less than or equal to 64 ksps, Ground shall use CCSDS LDPC rate ½ with codeword size of 256 octets for encoding and decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: The shorter codeword length is selected for lower symbol rates to reduce latency.

Note: FEC codes defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, are currently stated as only applicable to spacecraft-to-Earth and space-to-space links. However, in view of the symmetric property of the AOS space data link protocol, the CCSDS LDPC code can be applied to the AOS frames over Lunar Exploration Systems - Earth links. In order to reduce the burden on the links, we are using it over Earth - Lunar Exploration Systems links.

Comm-25: For symbol rates less than or equal to 64 ksps, Lunar Exploration Systems shall use CCSDS LDPC rate ½ with codeword size 256 octets for encoding and decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: The shorter codeword length is selected for lower symbol rates to reduce latency. .

Comm-26: Lunar Exploration Systems shall apply the Attached Sync Marker (ASM) defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Telemetry, Tracking, and Command link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½ or rate $^4/_5$ and the 32-bit CCSDS frame sync pattern identified for rate $^7/_8$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-27: Ground shall use the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames from Lunar Exploration Systems per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Telemetry, Tracking, and Command link.

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Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½ or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

TABLE 3.2.2.2-2 ASM FOR SELECTED LDPC CODES

	Rate ½ LDPC Code	*Rate $^{4}/_{5}$ LDPC Code*	*Rate $^{7}/_{8}$ LDPC Code*	*Uncoded*
ASM Length	64 bits	64 bits	32 bits	32 bits
ASM Pattern (hex)	034776C7272895B0	034776C7272895B0	1ACFFC1D	1ACFFC1D

Comm-28: Ground shall apply the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to Lunar Exploration Systems per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Telemetry, Tracking, and Command link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½ or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-29: Lunar Exploration Systems shall use the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames from Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Telemetry, Tracking, and Command link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½ or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame

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structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-30: Lunar Exploration Systems shall use bit randomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for randomization of transmitted data streams to Ground on the Telemetry, Tracking, and Command link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-31: Ground shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for derandomization of received data streams from Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-32: Ground shall use bit randomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for randomization of transmitted data streams to Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-33: Lunar Exploration Systems shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for derandomization of received data streams from Ground on the Telemetry, Tracking, and Command link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-34: When using BPSK, OQPSK and PCM/PSK/PM modulation schemes, Lunar Exploration Systems shall use NRZ-L encoding for transmission and reception of data streams to Ground on the Telemetry, Tracking, and Command link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding

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gain. NRZ-L symbol format encoding has better Energy per Bit-To-Noise Power Spectral Density Ratio (E_b/N_o) performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential encoding like NRZ-M.

Comm-35: When using BPSK, OQPSK and PCM/PSK/PM modulation schemes, Ground shall use NRZ-L encoding for transmission and reception of data streams to Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol format encoding has better E_b/N_o performance than differential symbol format encoding like NRZ-M. Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential encoding like NRZ-M.

Comm-36: Lunar Exploration Systems shall use the ASM for resolution of symbol phase ambiguity of received data streams from Ground on the Telemetry, Tracking, and Command link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like NRZ-M since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

Comm-37: Ground shall use the ASM for resolution of symbol phase ambiguity of received data streams from Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like NRZ-M since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

3.2.2.2.1.4 RANGING ON THE TELEMETRY, TRACKING, AND COMMAND LINK

Comm-38: Deleted

Comm-39: Lunar Exploration Systems shall use non-regenerative ranging with Ground using a PN chip rate of ≤ 4 megachips per second (Mcps) as defined in CCSDS 414.1-B-2, Pseudo-Noise (PN) Ranging Systems, on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to support radiometric tracking (ranging) to support GN&C. There is a Lunar Navigation Satellite System (LNSS) service identified as part of the LunaNet Interoperability

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Specification that may be used by Lunar Exploration Systems when it is implemented. ICSIS and LunaNet also specify radiometrics on the point-to-point Lunar Links identified in section 3.2.2.6. The system can choose between radiometric measurements on the DTE link, Lunar Link, LNSS, or all depending on their mission needs. The ranging mode selected for the DTE link provides for simultaneous data with ranging.

Comm-40: Ground shall use non-regenerative ranging with a chip rate of ≤ 4 Mcps with Lunar Exploration Systems to provide radiometric PN ranging as defined in CCSDS 414.1-B-2, Pseudo-Noise (PN) Ranging Systems, on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to support radiometric tracking/ranging to support GN&C since there are currently no "GPS" like capabilities. *The ranging mode selected provides for simultaneous data with ranging*.

Comm-41: Ground shall support tracking as defined in CCSDS 503.0-B-2, Tracking Data Message, on the Telemetry, Tracking, and Command link.

Rationale: This is the standard for radiometric data formats. It is relevant to the ground station-to-user Mission Operations Center (MOC) interface.

Comm-42: DELETE

3.2.2.2.1.5 DATA LINK LAYER FRAMING ON THE TELEMETRY, TRACKING, AND COMMAND LINK

The required standards for data link layer framing on the Telemetry, Tracking, and Command link are summarized in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, and expanded in this section.

Comm-43: Lunar Exploration Systems shall transmit data streams to Ground using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Note: CCSDS recently baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, the above standard (CCSDS 732.0-B-3, AOS Space Data Link Protocol) will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

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Comm-44: Ground shall receive data streams from Lunar Exploration Systems using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Note: CCSDS recently baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

Comm-45: Ground shall transmit data streams to Lunar Exploration Systems using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Note: CCSDS recently baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it on their respective ground stations, the above standard (CCSDS 732.0-B-3, AOS Space Data Link Protocol) will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

Comm-46: Lunar Exploration Systems shall receive data streams from Ground using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-1, Required Standards for Telemetry, Tracking, and Command Link, on the Telemetry, Tracking, and Command link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Note: CCSDS recently baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

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3.2.2.2.1.6 NETWORK LAYERS AND ABOVE ON THE TELEMETRY, TRACKING, AND COMMAND LINK

The sub-sections below address the standards for the layers of the protocol stack at and above the network layer, as illustrated in Figure 3.2.2.2.1.6-1, Protocol Stack – Options. To simplify the figure, the options for the Coding & Synchronization sub layer of the Data Link Layer are not explicitly shown in the figure. Lunar Exploration Systems will transmit and receive data using network-based applications with some exceptions for contingency operations. These applications will use either DTN or Internet Protocol (IP) to allow communications over the data link layer options described above and over multiple hops.

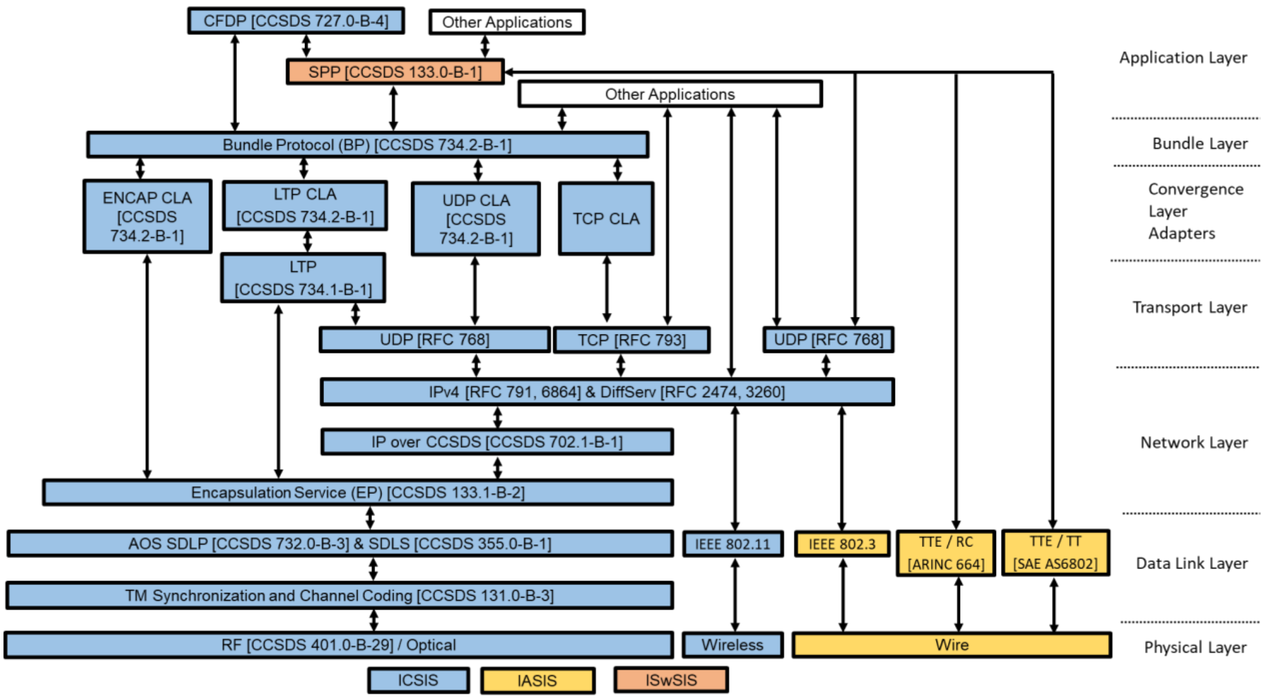

FIGURE 3.2.2.2.1.6-1 PROTOCOL STACK – OPTIONS

This document currently does not include any terrestrial interfaces in support of DTN and IP – this is part of the forward work defined in Section 4.0. CCSDS 901.1-M-1, Space Communications Cross Support--Architecture Requirements Document, provides a reference for that topic. A particular element may not need to implement all the applications listed in the following sections to support its mission objectives. However, for any applications in these sections that the element implements, it needs to follow the standards called out in the respective sections.

USLP is currently not included in the protocol stack. Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.

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3.2.2.2.1.6.1 NETWORK LAYER

Comm-47: Lunar Exploration Systems shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2, Encapsulation Service, when communicating over CCSDS Data Link Layer Protocols with Ground on the Telemetry, Tracking, and Command link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-48: Ground shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2, Encapsulation Service, when communicating over CCSDS Data Link Layer Protocols with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-49: Lunar Exploration Systems shall transmit and receive IP packets as defined in CCSDS 702.1-B-1, IP Over CCSDS Space Links, when using IP packets over CCSDS Data Link Layers with Ground MOC/MCC on the Telemetry, Tracking, and Command link.

Rationale: This allows IP packet use interoperability over CCSDS links. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

Comm-50: Ground MOC/MCC shall transmit and receive IP packets as defined in CCSDS 702.1-B-1, IP Over CCSDS Space Links, when using IP packets over CCSDS Data Link Layers with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: This allows IP packet use interoperability over CCSDS links. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

Comm-51: Lunar Exploration Systems shall use IP as specified in Internet Protocol version 4 (IPv4) (RFC 791, Internet Protocol) as a network layer with Ground MOC/MCC on the Telemetry, Tracking, and Command link.

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Rationale: IP provides for network layer services over interfaces that have low delay and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

Comm-52: Ground MOC/MCC shall use IP as specified in IPv4 (RFC 791, Internet Protocol) as a network layer with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: IP provides for network layer services over interfaces that have low delay and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

3.2.2.2.1.6.2 TRANSPORT LAYER

Comm-53: Lunar Exploration Systems shall **<TBR 3-7>** implement Licklider Transmission Protocol (LTP) as specified in CCSDS 734.1-B-1, Licklider Transmission Protocol (LTP) for CCSDS, on the Telemetry, Tracking, and Command link.

Rationale: LTP is a reliable point-to-point transport protocol, over which the bundle protocols will run. LTP is not expected to be used for all links, but was designed for long-haul links with high delay.

Comm-54: Lunar Exploration Systems shall implement Transmission Control Protocol (TCP) as specified in RFC 793, Transmission Control Protocol, on the Telemetry, Tracking, and Command link.

Rationale: TCP is a reliable transport protocol for use on IP networks.

Comm-55: Lunar Exploration Systems shall implement User Datagram Protocol (UDP) as specified in RFC 768, User Datagram Protocol, on the Telemetry, Tracking, and Command link.

Rationale: UDP provides best effort transport protocol for use on IP networks.

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3.2.2.2.1.6.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-56: Lunar Exploration Systems shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Telemetry, Tracking, and Command link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and Quality of Service (QoS) management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the Lunar Exploration Systems must have the capability to multiplex/demultiplex multiple data streams from multiple sources over heterogeneous links. Bundle Protocol Version 7 has been adopted by IETF and an update of CCSDS 734.2-B-1 is in work to update to version 7. This requirement will be updated to the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7.

Comm-57: **DELETED**

Comm-58: Lunar Exploration Systems should provide for the option to implement Internet Protocol Security (IPSec) over IP links. IPSec is specified in RFC 6071, IP Security (IPSec) and Internet Key Exchange (IKE) Document Roadmap.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

Comm-59: Lunar Exploration Systems shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Telemetry, Tracking, and Command link.

Rationale: In cases when bundle protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-60: Lunar Exploration Systems shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Telemetry, Tracking, and Command link.

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Rationale: In circumstances when bundle protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-61: Lunar Exploration Systems should implement the TCP Convergence Layer Adapter as specified in RFC 7242, Delay-Tolerant Networking TCP Convergence Layer Protocol, **<TBR 3-17>** on the Telemetry, Tracking, and Command link.

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242, Delay-Tolerant Networking TCP Convergence Layer Protocol, is in the experimental stage and not a finalized standard. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-62: Lunar Exploration Systems should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Telemetry, Tracking, and Command link.

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles. Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

3.2.2.2.1.6.4 APPLICATION LAYER

Comm-63: All applications transferring data over this interface shall use either DTN bundle protocol or IP as specified above on the Telemetry, Tracking, and Command link.

Rationale: This will allow all data flows to be routable by intermediate nodes. Any application that expects to flow data to and from Earth, either directly or relayed, should use BP to accommodate delays or end-to-end link availability. Though IP may work in some cislunar cases, use of BP will allow the application to also function in deep space cases.

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Comm-64: Lunar Exploration Systems shall use CCSDS File Delivery Protocol Class 1 and Class 2 as defined in CCSDS 727.0-B-4, CCSDS File Delivery Protocol (CFDP), to transmit and receive application layer files on the Telemetry, Tracking, and Command link.

Rationale: Provide reliable, accountable transfer of files – Class 2 is reliable, Class 1 is best effort. Class 3 and Class 4 are not required because not all Lunar Exploration partners implement these options. CCSDS 727.0-B-4 is now superseded by CCSDS 727.0-B-5, but not all systems are upgrading to version 5. Any implementation of version 5 must be compatible with version 4 to guarantee interoperability. The requirement will be updated to version 5 if all systems are interoperable with version 5 by upgrading or analysis has proven that version 4 and version 5 are compatible for Class 2 and Class 1 modes.

Comm-65: Lunar Exploration Systems should **<TBR 3-14>** use asynchronous message service (AMS) as defined in CCSDS 735.1-B-1, Asynchronous Message Service, to transmit and receive messages on the Telemetry, Tracking, and Command link.

Rationale: Provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient.

A common approach for monitoring the status of and sharing the information on routing in case of network disruption and delays will be needed in the future. Once such a standard is developed and agreed to by all the partners, it can be added to the document.

3.2.2.2.1.7 SECURITY ON THE TELEMETRY, TRACKING, AND COMMAND LINK

The following requirements define the security standards to ensure interoperability for the Telemetry, Tracking, and Command Lunar Exploration Systems - Ground links. The actual links and data to be protected, security and key management, etc. will be based on the International Partner agreement on security policies for the Program(s).

Comm-66: Lunar Exploration Systems shall implement CCSDS Cryptographic Algorithms, CCSDS 352.0-B-1, Advanced Encryption Standard (AES), for encryption/decryption of data exchanges with Ground on the Telemetry, Tracking, and Command link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197, Advanced Encryption Standard (AES).

Comm-67: Ground MOC/MCC shall implement CCSDS 352.0-B-1, CCSDS Cryptographic Algorithms, Advanced Encryption Standard (AES), for encryption/decryption of data exchanges with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

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Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197, Advanced Encryption Standard (AES). While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Comm-68: Lunar Exploration Systems shall implement the AES Galois/Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, with 256-bit keys, 96-bit Initialization Vectors (IV)s, with authentication tag lengths of 128-bits truncated to 64-bits for data exchanges with Ground on the Telemetry, Tracking, and Command link. Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement memorandum of understanding (MOU)/memorandum of agreement (MOA) agreements to handle applicable circumstances.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-69: Ground MOC/MCC shall implement the AES-GCM algorithm per NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, with 256-bit keys, 96-bit IVs, with authentication tag lengths of 128 bits truncated to 64 bits for data exchanges with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges. Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

Comm-70: Lunar Exploration Systems shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Ground on the Telemetry, Tracking, and Command link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-71: Ground MOC/MCC shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

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Rationale: Use CCSDS standards to ensure interoperability and compatibility. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Comm-72: Lunar Exploration Systems shall implement authentication as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Ground on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to support authentication in addition to encryption.

Comm-73: Ground MOC/MCC shall implement authentication as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Lunar Exploration Systems on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to support authentication in addition to encryption. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Comm-74: Lunar Exploration Systems shall be able to enable or disable encryption to support contingency operations with Ground on the Telemetry, Tracking, and Command link.

Rationale: Lunar Exploration Systems need to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-75: Ground MOC/MCC shall be able to enable or disable encryption to support contingency operations with *Lunar Exploration Systems* on the Telemetry, Tracking, and Command link.

Rationale: Ground needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

Comm-76: Lunar Exploration Systems shall employ key management techniques as defined in **<TBD 3-1>** with Ground on the Telemetry, Tracking, and Command link. (**<TBD 3-1>** could be Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures, as noted below).

Rationale: This requirement ensures that keys are managed in an interoperable manner.

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Note: CCSDS published the CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. If all partners agree to implement it, the requirement will be updated.

Comm-77: Ground MOC/MCC shall employ key management techniques as defined in **<TBD 3-1>** with Lunar Exploration Systems on the Telemetry, Tracking, and Command link. (**<TBD 3-1>** could be Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures, as noted below).

Rationale: This requirement ensures that keys are managed in an interoperable manner. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Note: CCSDS published the CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. If all partners agree to implement it, the requirement will be updated.

3.2.2.2.2 HIGH RATE COMMUNICATION LINKS

This subsection defines standards for high rate data transfer between Lunar Exploration Systems and Ground. Ka-band and Optical communication links are selected for this application. Ka-band is considered for Lunar Exploration Systems in accordance with CCSDS/SFCG recommendations because it has significantly more spectrum bandwidth available and there is no need for a ranging channel on the high rate link since the X-band Telemetry, Tracking, and Command link supports the ranging needs on Lunar Exploration Systems. Future capabilities may provide ranging on Ka-band and Ground currently supports fixed frequency carrier Doppler measurements on Ka-band.

NASA's DSN complexes and some International Partner Stations currently support Ka-band downlink for near-Earth missions. NASA's DSN currently supports Ka-band uplink for near-Earth at one complex and is in the process of adding near-Earth Ka-band uplink to the two other complexes. NASA NSN is planning on building or acquiring services for the Lunar Exploration Ground Stations (LEGS) capabilities that will provide Ka-band uplink and downlink. International partner stations do not provide Ka-band uplink for near-earth at this time. It is expected that Lunar Exploration Systems will require high-rate uplink capability to support human crews for medical, psychological, and performance reasons as well as to support large file uploads such as instructional videos, flight software updates, etc.

Optical links are selected for their power efficiency, i.e. ability to transfer large volumes of data over long distances at lower power than Ka-band, providing both a high rate uplink and downlink, and supporting very accurate range and time measurements. An optical link between Lunar Exploration Systems and Earth can support Lunar Exploration System utilization needs. This communication link will first be used to demonstrate and validate some of the optical communication and navigation technologies and then will become operational.

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3.2.2.2.2.1 HIGH RATE RF LINK

The required standards for the Lunar Exploration Systems - Ground high rate RF link are provided in Table 3.2.2.2-3, Minimum Standards for High Rate RF Link.

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TABLE 3.2.2.2-3 MINIMUM STANDARDS FOR HIGH RATE RF LINK SERVICE PROVIDERS[8]

Ka-band Forward Link (22.55 - 23.15 GHz)[6] (Earth to Lunar Exploration Systems)					
Symbol Rates[1,10]	**Modulation and Encoding[1, 9]**	**Ranging[11]**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
2 Msps ≤ symbol rate (Target rates are ~ 50 Msps)	Filtered OQPSK + NRZ-L	No	Code Rates ½, 4/5, 7/8, uncoded. Depending on the codeword selected, the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • Uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[7]
Ka-band Return Link (25.5 GHz – 27.0 GHz)[6] (Lunar Exploration Systems to Earth)					
Symbol Rates[1]	**Modulation and Encoding[1, 9]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
2 Msps ≤ symbol rate (Target rates are ~200Msps)	Filtered OQPSK + NRZ-L	No	Code Rates ½, 4/5, 7/8, uncoded. Depending on the codeword selected, the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • Uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[7]

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter. **The symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation**
2. N/A
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
8. Users of these services may select the capabilities required to implement the end-to-end interoperable link configurations needed for their mission to be ICSIS compliant.
9. The LCAWG recommended GMSK. Given that not all partner Ground stations currently implement GMSK, the ICSIS baseline is OQPSK instead of GMSK. Once all the partners implement GMSK on the infrastructure side, this will become a part of the interoperability standard.
10. Uncoded modes are only for contingencies and do not need to be supported over the full range of symbol rates.
11. Standards for ranging on Ka-band may be identified in the future. These may become part of the interoperability standard once all partners implement them on the infrastructure side.

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3.2.2.2.2.1.1 FREQUENCY FOR HIGH RATE RF LINKS

Comm-78: Lunar Exploration Systems shall use 25.5 - 27 gigahertz (GHz) (Ka-band) frequency band to transmit signals to Ground on the High Rate RF link.

Rationale: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-79: Ground shall use 25.5 - 27 GHz (Ka-band) frequency band to receive signals from Lunar Exploration Systems on the High Rate RF link.

Rationale: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-80: Ground shall use 22.55 – 23.15 GHz (Ka-band) frequency band to transmit signals to Lunar Exploration Systems on the High Rate RF link.

Rationale: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-81: Lunar Exploration Systems shall use 22.55 – 23.15 GHz (Ka-band) frequency band to receive signals from Ground on the High Rate RF link.

Rationale: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

3.2.2.2.2.1.2 MODULATION ON HIGH RATE RF LINKS

The required standards for modulation on the High Rate RF link are summarized in Table 3.2.2.2-3, Required Standards for High Rate RF Link, and expanded in this section.

Comm-82: Lunar Exploration Systems shall implement filtered OQPSK to transmit signals to Ground as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the High Rate RF link.

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Rationale: Filtered OQPSK provides spectral efficiency and interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

Comm-83: Ground shall implement filtered OQPSK to receive signals from Lunar Exploration Systems as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the High Rate RF link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

Comm-84: Ground shall implement filtered OQPSK to transmit signals to Lunar Exploration Systems as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the High Rate RF link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

Note: OQPSK defined in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, is not listed as a choice for uplinks. However, in view of the symmetric property of the AOS space data link protocol, OQPSK can be used on the uplinks. The CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft standard is being updated to include this mode on the uplinks.

Comm-85: Lunar Exploration Systems shall implement filtered OQPSK to receive signals from Ground as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the High Rate RF link.

Rationale: Filtered OQPSK carrier provides spectral efficiency and interoperability between Lunar Exploration Systems and NASA/International Partner and other ground stations; provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

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Note: OQPSK defined in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, is not listed as a choice for uplinks. However, in view of the symmetric property of the AOS space data link protocol, OQPSK can be used on the uplinks. The CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft standard is being updated to include this mode on the uplinks.

3.2.2.2.2.1.3 CODING AND SYNCHRONIZATION ON HIGH RATE RF LINKS

The required standards for coding and synchronization on the High Rate RF link is summarized in Table 3.2.2.2-3, Required Standards for High Rate RF Link, and expanded in this section.

Comm-254: Lunar Exploration Systems shall be able to enable or disable FEC to support contingency operations with Ground on the High Rate RF link.

Rationale: Lunar Exploration Systems need to be able to enable or disable FEC to support contingency and other operational scenarios. Uncoded modes are supported for lower range of symbol rates since they are used for contingency and are not used to specify or drive the performance of the Comm systems.

Comm-255: Ground shall be able to enable or disable FEC to support contingency operations with Lunar Exploration Systems on the High Rate RF link.

Rationale: Lunar Exploration Systems need to able to enable or disable FEC to support contingency and other operational scenarios. Uncoded modes are supported for lower range of symbol rates since they are used for contingency and are not used to specify or drive the performance of the Comm systems.

Comm-86: Lunar Exploration Systems shall use CCSDS Low Density Parity Codes, rate ½, rate $^4/_5$, or rate $^7/_8$ for encoding data to Ground as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

Comm-87: Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^4/_5$, and rate $^7/_8$ for decoding data from Lunar Exploration Systems as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

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Comm-88: Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^4/_5$, and rate $^7/_8$ for encoding data to Lunar Exploration Systems as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF, on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

Note: FEC codes defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, are currently stated as only applicable to spacecraft-to-Earth and space-to-space links. However, in view of the symmetric property of the AOS space data link protocol, the CCSDS LDPC code can be applied to the AOS frames over Lunar Exploration Systems-Earth links. In order to reduce the burden on the links, we are using it over Ground-to-Lunar Exploration System links.

Comm-89: Lunar Exploration Systems shall use CCSDS Low Density Parity Codes, rate ½, rate $^4/_5$, or rate $^7/_8$ for decoding data from Ground as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

Comm-90: Lunar Exploration Systems shall apply the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the High Rate RF link.

Rationale: The use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½ or rate $^4/_5$ and the 32-bit CCSDS frame sync pattern identified for rate $^7/_8$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-91: Ground shall use the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames from Lunar Exploration Systems per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the High Rate RF link.

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Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-92: Ground shall apply the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to Lunar Exploration Systems per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the High Rate RF link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-93: Lunar Exploration Systems shall use the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames from Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the High Rate RF link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½ or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-94: Lunar Exploration Systems shall use bit randomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for randomization of transmitted data streams to Ground on the High Rate RF link.

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Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-95: Ground shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for derandomization of received data streams from Lunar Exploration Systems on the High Rate RF link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-96: Ground shall use bit randomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for randomization of transmitted data streams to Lunar Exploration Systems on the High Rate RF link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-97: Lunar Exploration Systems shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for derandomization of received data streams from Ground on the High Rate RF link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Comm-98: Lunar Exploration Systems shall use NRZ-L encoding for transmission of data streams to Ground on the High Rate RF link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol format encoding has better E_b/N_o *performance than differential symbol format encoding like NRZ-M. Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential encoding like NRZ-M.*

Comm-99: Ground shall use NRZ-L encoding for transmission of data streams to Lunar Exploration Systems on the High Rate RF link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding

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gain. NRZ-L symbol format encoding has better E_b/N_o performance than differential symbol format encoding like NRZ-M. Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential encoding like NRZ-M.

Comm-100: Lunar Exploration Systems shall use the ASM for resolution of symbol phase ambiguity of received data streams from Ground on the High Rate RF link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like NRZ-M since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

Comm-101: Ground shall use the ASM for resolution of symbol phase ambiguity of received data streams from Lunar Exploration Systems on the High Rate RF link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like NRZ-M since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

3.2.2.2.2.1.4 RADIOMETRICS ON HIGH RATE RF LINKS

The baseline DTE RF link identified in ICSIS for radiometrics is the Telemetry, Tracking, and Command link, but there are discussions for supporting ranging on the High-Rate Ka-band DTE link. Most ground systems already support measurement of fixed frequency carrier Doppler. This section is a placeholder for any radiometric standards on the High Rate Ka-band DTE link that are agreed to by the representative missions, infrastructure, and International Partners for inclusion in ICSIS for interoperability.

3.2.2.2.2.1.5 DATA LINK LAYER FRAMING ON HIGH RATE RF LINKS

The required standards for data link layer framing on the High Rate RF link are summarized in Table 3.2.2.2-3, Required Standards for High Rate RF Link, and expanded in this section.

Comm-102: Lunar Exploration Systems shall transmit data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, to Ground on the High Rate RF link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

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Note: CCSDS baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

Comm-103: Ground shall receive data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, from Lunar Exploration Systems on the High Rate RF link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems *and NASA/International Partner ground stations*.

Note: CCSDS baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

Comm-104: Ground shall transmit data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, to Lunar Exploration Systems on the High Rate RF link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Note: CCSDS baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

Comm-105: Lunar Exploration Systems shall receive data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.2-3, Required Standards for High Rate RF Link, from Ground on the High Rate RF link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between Lunar Exploration Systems and NASA/International Partner ground stations.

Note: CCSDS baselined the CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

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3.2.2.2.2.1.6 NETWORK LAYER AND ABOVE FOR HIGH RATE RF LINKS

The sub-sections below address the standards for the layers of the protocol stack at the network layer and above, as illustrated in Figure 3.2.2.2.1.6-1, Protocol Stack – Options. To simplify the figure, the options for the Coding and Synchronization sub layer of the Data Link Layer are not explicitly shown in figure. Please refer to Section 3.2.2.2.1.6 for additional descriptions.

3.2.2.2.2.1.6.1 NETWORK LAYER

Comm-106: Lunar Exploration Systems shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2, Encapsulation Service, when communicating over CCSDS Data Link Layer Protocols with Ground on the High Rate RF link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-107: Ground shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2, Encapsulation Service, when communicating over CCSDS Data Link Layer Protocols with Lunar Exploration Systems on the High Rate RF link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-108: Lunar Exploration Systems shall transmit and receive IP packets as defined in CCSDS 702.1-B-1, IP Over CCSDS Space Links when using IP packets over CCSDS Data Link Layers with Ground MOC/MCC on the High Rate RF link.

Rationale: This allows IP packet use interoperability over CCSDS links. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

Comm-109: Ground MOC/MCC shall transmit and receive IP packets as defined in CCSDS 702.1-B-1, IP Over CCSDS Space Links, when using IP packets over CCSDS Data Link Layers with Lunar Exploration Systems on the High Rate RF link.

Rationale: This allows IP packet use interoperability over CCSDS links. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the IP protocol functions are usually

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between Lunar Exploration Systems and MOC/MCC and not at the ground stations.

Comm-110: Lunar Exploration Systems shall use IP as specified in IPv4 (RFC 791, Internet Protocol) as a network layer with Ground on the High Rate RF link.

Rationale: IP provides for network layer services over interfaces that have low delay and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

Comm-111: Ground shall use IP as specified in IPv4 (RFC 791, Internet Protocol) as a network layer with Lunar Exploration Systems on the High Rate RF link.

Rationale: IP provides for network layer services over interfaces that have low delay and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

3.2.2.2.2.1.6.2 TRANSPORT LAYER

Comm-112: Lunar Exploration Systems shall **<TBR 3-7>** implement LTP as specified in CCSDS 734.1-B-1, Licklider Transmission Protocol (LTP) for CCSDS, on the High Rate RF link.

Rationale: LTP is a reliable point-to-point transport protocol, over which the bundle protocols will run. LTP is not expected to be used for all links, but was designed for long-haul links with high delay.

Comm-113: Lunar Exploration Systems shall implement TCP as specified in RFC 793, Transmission Control Protocol, on the High Rate RF link.

Rationale: TCP is a reliable transport protocol for use on IP networks.

Comm-114: Lunar Exploration Systems shall implement UDP as specified in RFC 768, User Datagram Protocol, on the High Rate RF link.

Rationale: UDP provides best effort transport protocol for use on IP networks.

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3.2.2.2.2.1.6.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-115: Lunar Exploration Systems shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the High Rate RF link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the Lunar Exploration Systems must have the capability to multiplex/demultiplex multiple data streams from multiple sources over heterogeneous links. Bundle Protocol Version 7 has been adopted by IETF and an update of CCSDS 734.2-B-1 is in work to update to version 7. This requirement will be updated to the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7.

Comm-116: DELETED

Comm-117: Lunar Exploration Systems should provide for the option to implement IPSec over IP links. IPSec is specified in RFC 6071, IP Security (IPSec) and Internet Key Exchange (IKE) Document Roadmap.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk.

Comm-118: Lunar Exploration Systems shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the High Rate RF.

Rationale: In cases when bundle protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-119: Lunar Exploration Systems shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the High Rate RF link.

Rationale: In circumstances when bundle protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that

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all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-120: Lunar Exploration Systems should implement the TCP Convergence Layer Adapter as specified in RFC 7242, Delay-Tolerant Networking TCP Convergence Layer Protocol, **<TBR 3-17>** on the High Rate RF link.

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242, Delay-Tolerant Networking TCP Convergence Layer Protocol, is in the experimental stage and not a finalized standard. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-121: Lunar Exploration Systems should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the High Rate RF link.

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles. Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

3.2.2.2.2.1.6.4 APPLICATION LAYER

Comm-122: All applications transferring data over this interface shall use either DTN Bundle Protocol or IP as specified above on the High Rate RF link.

Rationale: This will allow all data flows to be routable by intermediate nodes. Any application that expects to flow data to and from Earth either directly or relayed should use BP to accommodate delays or end-to-end link availability. Though IP may work in some cislunar cases, use of BP will allow the application to also function in deep space cases.

Comm-123: Lunar Exploration Systems shall use CCSDS File Delivery Protocol Class 1 and Class 2 as defined in CCSDS 727.0-B-4, CCSDS File Delivery Protocol (CFDP), to transmit and receive application layer files on the High Rate RF link.

Rationale: Provide reliable, accountable transfer of files – Class 2 is reliable, Class 1 is best effort. Class 3 and Class 4 are not required because not all Lunar Exploration Systems partners implement these

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options. CCSDS 727.0-B-4 is now superseded by CCSDS 727.0-B-5, but not all systems are upgrading to version 5. Any implementation of version 5 must be compatible with version 4 to guarantee interoperability. The requirement will be updated to version 5 if all systems are interoperable with version 5 by upgrading or analysis has proven that version 4 and version 5 are compatible for Class 2 and Class 1 modes.

Comm-124: Lunar Exploration Systems should **<TBR 3-14>** use AMS as defined in CCSDS 735.1-B-1, Asynchronous Message Service, to transmit and receive messages on the High Rate RF link.

Rationale: AMS provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient.

3.2.2.2.2.1.7 SECURITY ON HIGH RATE RF LINKS

The following requirements define the security standards to ensure interoperability for the High Rate RF Lunar Exploration Systems - Ground links. The actual links and data to be protected, security and key management, etc. will be based on the International Partner agreement on security policies for the Program(s).

Comm-125: Lunar Exploration Systems shall implement CCSDS Cryptographic Algorithms, CCSDS 352.0-B-1, Advanced Encryption Standard (AES), for encryption and decryption **<TBR 3-15>** of data exchanges with Ground on the High Rate RF link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197, Advanced Encryption Standard (AES).

Comm-126: Ground MOC/MCC shall implement CCSDS 352.0-B-1, CCSDS Cryptographic Algorithms, Advanced Encryption Standard (AES), for encryption **<TBR 3-15>** and decryption of data exchanges with Lunar Exploration Systems on the High Rate RF link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197, Advanced Encryption Standard (AES). While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Comm-127: Lunar Exploration Systems shall implement the AES-GCM algorithm per NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, with 256-bit keys, 96-bit IVs, with authentication tag lengths of 128-bits truncated to 64-bits for data exchanges with Ground on the High Rate RF link.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges. Programs need to assess the level of Security Information Assurance and

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Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances.

Comm-128: Ground MOC/MCC shall implement the AES-GCM algorithm per NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, with 256-bit keys, 96-bit IVs, with authentication tag lengths of 128-bits truncated to 64-bits for data exchanges with Lunar Exploration Systems on the High Rate RF link.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges. Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Comm-129: Lunar Exploration Systems shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Ground on the High Rate RF link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-130: Ground MOC/MCC shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Lunar Exploration Systems on the High Rate RF link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

Comm-131: Lunar Exploration Systems shall implement authentication as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Ground on the High Rate RF link.

Rationale: Lunar Exploration Systems need to support authentication in addition to encryption.

Comm-132: Ground MOC/MCC shall implement authentication as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges with Lunar Exploration Systems on the High Rate RF link.

Rationale: Lunar Exploration Systems need to support authentication in addition to encryption. While Ground can be the ground station or the

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ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

Comm-133: Lunar Exploration Systems shall be able to enable or disable encryption to support contingency operations with Ground on the High Rate RF link.

Rationale: Lunar Exploration Systems need to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-134: Ground MOC/MCC shall be able to enable or disable encryption to support contingency operations with Lunar Exploration Systems on the High Rate RF link.

Rationale: Ground needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

Comm-135: Lunar Exploration Systems shall employ key management techniques as defined in **<TBD 3-1>** with Ground on the High Rate RF link. (**<TBD 3-1>** could be Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures, as noted below).

Rationale: This requirement ensures that keys are managed in an interoperable manner.

Note: CCSDS published the CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. If all partners agree to implement it, this requirement will be updated.

Comm-136: Ground MOC/MCC shall employ key management techniques as defined in **<TBD 3-1>** with Lunar Exploration Systems on the High Rate RF link. (**<TBD 3-1>** could be Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures, as noted below).

Rationale: This requirement ensures that keys are managed in an interoperable manner. While Ground can be the ground station or the ground station in conjunction with the MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Note: CCSDS published the CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. If all partners agree to implement it, this requirement will be updated.

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3.2.2.2.2.2 OPTICAL LINKS

Optical links between Lunar Exploration Systems and Earth will be used to validate performance and extensibility to deep space as well as to augment/provide higher rate links and very accurate optimetric ranging for Lunar Exploration Systems and Lunar Exploration Systems utilization. The CCSDS has developed a High-Photon Efficiency (HPE) optical communications recommendation suitable for deep space and lunar vicinity optical links. The IOAG has endorsed a CCSDS recommendation to use HPE for Lunar Exploration Systems to Earth trunk lines, Orbiting Lunar Assets to lunar surface, and Lunar Exploration Systems to nearby spacecraft; basically for all optical links in the lunar vicinity. The HPE recommendations are documented in CCSDS 141.0-B-1, Optical Communications Physical Layer, and in CCSDS 141.1-B-1, Optical Communications Coding and Synchronization. These books define the downlink and uplink optical waveforms, coding, and synchronization. This section will be updated to include the relevant standard and specifications when agreed to implement and add to document.

<TBD 3-5> – standards for Optical Communication and Optimetrics.

3.2.2.2.3 CONTINGENCY COMMUNICATION LINKS

<TBD 3-8> – standards for Contingency Communication links including defining what constitutes a “contingency”, “emergency”.

Contingency communications between the spacecraft and earth provide the lifeline for spacecraft during off nominal or emergency situations. The protocols and signaling to support contingency communications need to be simple, and implemented by majority of the ground stations worldwide to enable cross-support to an ailing spacecraft. The IOAG-LCAWG is looking into the standards and protocols to support contingency communications and tracking. The technical basis for cross-support lies in implementing the spectrum and communication protocols which are consistent with the IOAG LCAWG draft study recommendations as the basis for interoperability. A summary of these draft standards is given in Table 3.2.2.2-4, Draft Required Standards for Contingency Communication Link. As we work with the IOAG LCAWG, we will re-look at the frequency band and radiometrics for the contingency link.

The current symbol rates shown in Table 3.2.2.2-4, Draft Required Standards for Contingency Communication Link are NOT intended to support contingency voice communications. When a crew is at an Lunar Exploration Target Vehicle, the vehicle they arrived in (Orion, et.al.) is responsible for providing their redundant contingency voice loop(s) with Earth. The crew can use the emergency audio in the crewed vehicle (example: Orion’s Emergency Comm. system) if necessary; and when the Lunar Exploration System is uncrewed, a low-rate uplink is sufficient to command the Lunar Exploration System. Once the recommended standards and protocols have been agreed to by the partners, this section will be updated with the corresponding detailed requirements.

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TABLE 3.2.2.2-4 DRAFT REQUIRED STANDARDS FOR CONTINGENCY COMMUNICATION LINK

X-band Forward Link (7190-7235 MHz)[6] (Earth to Lunar Exploration Systems) Emergency/Contingency					
Symbol Rates[1,9]	**Modulation and Encoding[1,9]**	**Ranging**	**Coding[4]**	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
0.5 ≤ symbol rate ≤ 4 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]	Option 1 – BCH Option 2 – LDPC[4] LDPC Code rate ½ using the following codeword size and ASM: • 128 octets plus 64 bit ASM	• 128 octets for LDPC rate ½	CCSDS Space Data Link Security Protocol[7]
X-band Return Link (8450-8500 MHz)[6] (Lunar Exploration Systems to Earth) Emergency/Contingency					
Symbol Rates[1,9]	**Modulation and Encoding[1,9]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
0.1[8] ≤ symbol rate ≤ 20 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]	Option 1 – (Concatenated Convolution + Reed Solomon)[4] Option 2 – LDPC[4] LDPC Code rate ½ using the following codeword size and ASM: • 128 octets plus 64 bit ASM	128 octets for LDPC rate ½	CCSDS Space Data Link Security Protocol[7]

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter. **The symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation**
2. CCSDS PN Ranging, Non-regenerative. Ranging chip rate: ≤ 2 Mcps per CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems, Blue Book
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
8. Lower limit based on ECSS (European Cooperation Space Standardization/CCSDS. User symbol rates lower than 0.1 ksps can be supported on a case-by-case basis.
9. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (Future version of 401.0 will address higher PCM/PSK/PM symbol rates.)

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3.2.2.3 LUNAR EXPLORATION SYSTEM – RENDEZVOUS COMMUNICATION LINKS

The Lunar Exploration Target Vehicle – Visiting Vehicle link is the Space-to-Space link between a Lunar Exploration Target Vehicle and visiting vehicles such as Orion, logistics modules, or another Lunar Exploration System, etc. The VV will rendezvous and dock/berth to the Lunar Exploration Target Vehicles. The Lunar Exploration Target Vehicle - VV link will be used to exchange information and for radiometric tracking. This link is compatible with the Orion Space-to-Space (aka rendezvous) link that will be used during Orion rendezvous, proximity operations and docking with a Lunar Exploration Target Vehicle. The detailed breakdown of data transferred between Lunar Exploration Target Vehicle and a VV is given in Appendix D.

The Lunar Exploration Target Vehicle-VV S-band link is designed to support Space-to-Space radiometric tracking to provide range and Doppler measurements. The system, in Point B mode, generates, modulates, and transmits the range PN code on the Q channel (range channel); and it receives and processes the coherent turn-around carrier and range PN code on the Q channel to obtain the range and Doppler measurements. The system, in Point A mode, coherently retransmits the received carrier and the range PN code on the Q channel based on the signal it receives to support radiometric measurements. Once docked to Lunar Exploration Target Vehicle, the VV will have a hardline interface with the Lunar Exploration Target Vehicle via a docking system. This hardline interface will be used to transfer data between the VV and Lunar Exploration Target Vehicle as defined in IASIS.

Example use case (Orion docking to Gateway): Gateway (Lunar Exploration Target Vehicle) S-band system can support both Point A and Point B mode. In this example, the S-band system on Gateway is in Point A mode and Orion (Visiting Vehicle) is in Point B mode. Orion generates, modulates, and transmits the ranging channel; Gateway receives and coherently turns it around. Orion receives, demodulates and processes the range channel and carrier to make the range and range rate measurements. Once docked to Gateway, Orion will use the hardline interface with Gateway via the docking system to exchange data with Gateway, and Orion data will be relayed by Gateway to/from Earth.

The Lunar Exploration Target Vehicle could choose to implement the Point A side, the Point B side or both. If the Lunar Exploration Target Vehicle implements the Point A side, than the VV must implement the Point B side; if the Lunar Exploration Target Vehicle implements the Point B side, the VV must implement the Point A side. If the Lunar Exploration Target Vehicle implements both like Gateway, than it can configure its system to support the needs of the VV. These interface requirements must be coordinated and defined in the respective cross program/project requirements and interface documents.

3.2.2.3.1 FREQUENCY FOR RENDEZVOUS LINK

The following section requirements are written in terms of the Point A side and the Point B side – agnostic of which one is the Lunar Exploration Target Vehicle and which one is the VV. The Lunar Exploration Target Vehicle requirements and respective IRDs, in coordination with the VVs will define the roles of Point A/B.

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Comm-137: The Point A side shall use 2200-2290 MHz (S-band) frequency band to transmit signals to the Point B side.

Rationale: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle to be compatible with Orion S-band system. The S-band frequency pairs used for this link will be captured in the Lunar Exploration System-VV Interface Requirements Documents (IRDs). Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-138: The Point B side shall use 2200-2290 MHz (S-band) frequency band to receive signals from the Point A side.

Rationale: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle to be compatible with Orion S-band system. The S-band frequency pairs used for this link will be captured in the Lunar Exploration Systems-VV Interface Requirements Documents (IRDs). Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-139: The Point A side shall use 2025-2110 MHz (S-band) frequency band to receive signals from the Point B side.

Rationale: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle to be compatible with Orion S-band system. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-140: The Point B side shall use 2025-2110 MHz (S-band) frequency band to transmit signals to the Point A side.

Rationale: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle to be compatible with Orion S-band system. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

3.2.2.3.2 MODULATION AND SIGNAL CHARACTERISTICS ON RENDEZVOUS LINK

The following section requirements are written in terms of the Point A side and the Point B side – agnostic of which one is the Lunar Exploration Target Vehicle and which one is the VV. The Lunar Exploration System requirements and respective IRDs will define the roles of Point A/B as well as specify PN codes for the links. The PN codes must be coordinated to ensure minimal interference from users in the Lunar regions. The modulation and signal characteristics were defined based on signal structures in the

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Space Network Users' Guide (SNUG) when Orion's capabilities were being defined. CCSDS 415.1-B-1 specifies modulation and signal characteristics that are consistent with those ICSIS specifies from SNUG, but for Data Relay Satellites instead of Rendezvous operations.

Comm-141: The Point B side shall generate and transmit the carrier, short and long PN codes to the Point A side.

Rationale: The Point B will act like the Space Network ground terminal as described in 450-SNUG, Space Network Users' Guide (SNUG).

Comm-142: The Point A side shall coherently retransmit the received carrier with a turn-around ratio of 240/221(transmit/receive) for coherent Rendezvous operations.

Rationale: The 240/221 turn-around ratio is required to be compatible with Orion and is described in the 450-SNUG, Space Network Users' Guide (SNUG). Coherent link operation is required for providing the radiometric measurements of range and range rate.

Comm-143: The Point A side shall coherently retransmit the received range channel data to the Point B side.

Rationale: In order to provide range data at the Point B, the received range channel data at the Point A side must be coherently retransmitted to Point B side.

Comm-144: The Point A side shall provide a non-coherent mode of operation on Rendezvous links.

Rationale: Non-coherent operation is required in order that Point A side can deliver telemetry when it does not receive a signal from the Point B side. When two-way radiometric measurements are not required, a non-coherent mode of operation may be preferred since signal acquisition and tracking is easier, faster, and requires a lower E_b/N_o.

Comm-145: The Point A side shall automatically switch to a non-coherent mode of operation on Rendezvous links if it loses the signal from the Point B side.

Rationale: Without automatic switching to non-coherent mode, loss of the signal from Point B side could cause the Point A side to stop transmitting as well. A good option is to "freeze" the current carrier frequency and PN chip rate when the link from the Point B side is lost, and maintain the same modulation on Point A side transmission to the Point B side.

Comm-146: The Point B side shall process the received carrier to make radiometric measurements of one-way or two-way Doppler data for the Rendezvous links.

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Rationale: The Point B vehicle should measure one-way Doppler (non-coherent Point A) or two-way Doppler (coherent Point A) to support rendezvous maneuvering.

Comm-147: The Point B side shall process the coherent turned-around ranging channel data to provide radiometric measurements of range data for the Rendezvous links.

Rationale: The Point B vehicle should measure range to the Point A to support rendezvous maneuvering.

Comm-148: The Point B side shall receive signals with modulation schemes in accordance with Table 3.2.2.3-1, Point A Signal Characteristics for Rendezvous Links.

Rationale: Proximity modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Space Network Users' Guide (SNUG), Section 6.3 for the Space Network (SN). The SN Data Group 1 (DG)1/mode 3 and DG2 modulations are supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with higher data rates.

Comm-149: The Point A side shall transmit signals with modulation schemes in accordance with Table 3.2.2.3-1, Point A Signal Characteristics for Rendezvous Links.

Rationale: Proximity modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Space Network Users' Guide (SNUG), Section 6.3 for the SN. The SN DG1/mode 3 and DG2 modulations are supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with higher data rates.

Comm-150: The Point A side shall transmit one data stream using alternate symbols on the inphase (I) and quadrature (Q) modulation channels when using DG1 mode 1, DG1 mode 2, or DG2.

Rationale: DG1 can accept either one data stream (split between I and Q channels) or two independent data streams. Use of one data stream split between I and Q channels is chosen to be compatible with Orion.

Comm-151: The Point B side shall receive one data stream using alternate symbols on the I and Q modulation channels when using DG1 mode 1, DG1 mode 2, or DG2.

Rationale: DG1 can accept either one data stream (split between I and Q channels) or two independent data streams. Use of one data stream split between I and Q channels is chosen to be compatible with Orion.

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Comm-152: The Point A side shall transmit one data stream on the Q modulation channel and a PN ranging code on the I modulation channel when using DG1 mode 3.

Rationale: DG1 mode 3 is used when both PN code ranging and a higher data rate than can be accommodated by DG1 mode 1 or 2 is desired. DG1 mode 3 accepts a high data rate stream on the Q channel. DG1 mode 3 can accept either a Low Data Rate (LDR) stream on the I channel with the ranging code or no data on the I channel with the ranging code. One data stream on the Q channel is used to be compatible with Orion.

Comm-153: The Point B side shall receive one data stream on the Q modulation channel and a PN ranging code on the inphase (I) modulation channel when using DG1 mode 3.

Rationale: DG1 mode 3 is used when both PN code ranging and a higher data rate than can be accommodated by DG1 mode 1 or 2 is desired. DG1 mode 3 accepts a high data rate stream on the Q channel. DG1 mode 3 can accept either a LDR stream on the I channel with the ranging code or no data on the I channel with the ranging code. One data stream on the Q channel is used to be compatible with Orion.

TABLE 3.2.2.3-1 POINT A SIGNAL CHARACTERISTICS FOR RENDEZVOUS LINKS

Link Type Coded	Symbol Rate	Data Group	Mode	Doppler Measurement	PN Ranging	Modulation	PN Spreading
DG1 coherent mode 1	>= 18 Ksps <= 600 Ksps	DG1 Coherent	Mode 1	Two-Way	Yes	Balanced SQPN	Yes
DG1 non-coherent mode 2	>= 18 Ksps <= 600 Ksps	DG1 Non-Coherent	Mode 2	One-Way	No	Balanced SQPN	Yes
DG1 coherent mode 3	>= 18 Ksps <= 6 Msps	DG1 Coherent	Mode 3	Two-Way	Yes	Spread Spectrum (I Only) Unbalanced QPSK[1]	Yes
DG2 coherent	>= 600 Ksps <= 6 Msps	DG2 Coherent	-	Two-Way	No	Balanced SQPSK	No
DG2 non-coherent	>= 300 Ksps <= 6 Msps	DG2 Non-Coherent	-	One-Way	No	Balanced SQPSK	No
DG2 non-coherent	>= 6 Msps <= 20 Msps	DG2 Non-Coherent	-	One-Way	No	Balanced SQPSK	No

Note: (1) Power ratio is (1:4), I-channel is PN-only, and Q-channel is data-only

Comm-154: The Point B side shall transmit signals to Point A side using Spread Spectrum Unbalanced Quadriphase Shift Keying (SS-UQPSK) modulation as shown in Table 3.2.2.3-2, Point B Signal Characteristics for Rendezvous Links.

Rationale: Proximity modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Space Network Users' Guide (SNUG), Section 6.2 for the SN. The SS-

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UQPSK modulation is supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with low data rates.

Comm-155: The Point A side shall receive signals from Point B side with SS-UQPSK modulation schemes in accordance with Table 3.2.2.3-2, Point B Signal Characteristics for Rendezvous Links.

Rationale: Modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Space Network Users' Guide (SNUG), Section 6.3 for the SN. The SS-UQPSK modulation is supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with low data rates.

TABLE 3.2.2.3-2 POINT B SIGNAL CHARACTERISTICS FOR RENDEZVOUS LINKS

Link Type	Coded Symbol Rate	PN Ranging	Modulation	PN Spreading
SQPN 1	>= 18 Ksps <= 300 Ksps	Yes	Spread Spectrum Unbalanced QPSK (10:1)	Yes

3.2.2.3.3 ANTENNA POLARIZATION ON RENDEZVOUS LINK

Comm-156: The Lunar Exploration Target Vehicle shall transmit using right hand circular polarization on the Rendezvous links.

Rationale: Right-Hand Circular Polarization (RHCP) is selected to be compatible with Orion.

Comm-157: The Lunar Exploration Target Vehicle shall receive using right hand circular polarization on Rendezvous links.

Rationale: RHCP is selected to be compatible with Orion.

Comm-158*:* VV shall transmit using right hand circular polarization on Rendezvous links.

Rationale: RHCP is selected to be compatible with Orion.

Comm-159: VV shall receive using right hand circular polarization on Rendezvous links.

Rationale: RHCP is selected to be compatible with Orion.

3.2.2.3.4 CODING AND SYNCHRONIZATION ON RENDEZVOUS LINK

The following section requirements are common to both Point A and Point B systems (common to both sides of the Lunar Exploration Target Vehicle–VV interface).

Comm-160: The Lunar Exploration Target Vehicle and VV shall use CCSDS Rate 1/2 k=1024 Low Density Parity Code as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, for encoding data on Rendezvous links.

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Rationale: Coding gain provided by LDPC codes is ~2 dB more than that provided by concatenated Reed-Solomon/convolutional codes. Using rate ½ LDPC code to be compatible with Orion.

Comm-161: The Lunar Exploration Target Vehicle and VV shall use CCSDS Rate ½ k=1024 Low Density Parity Code as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, for decoding data on Rendezvous links

Rationale: Coding gain provided by LDPC codes is ~2 dB more than that provided by concatenated Reed-Solomon/convolutional codes. Using rate ½ LDPC code to be compatible with Orion.

Comm-162: The Lunar Exploration Target Vehicle and VV shall enable and disable communication link FEC on Rendezvous links upon receipt of command.

Rationale: Lunar Exploration Target Vehicle needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-163: The Lunar Exploration Target Vehicle and VV shall apply the 64-bit ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 8, to transmitted frames on the Rendezvous links.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for Rate ½ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between the Lunar Exploration Target Vehicle and VV. Using the same 64-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames.

Comm-164: The Lunar Exploration Target Vehicle and VV shall use the 64-bit ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 8, for synchronization of received frames on the Rendezvous links.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for Rate ½, 2/3, and 4/5 LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between the the Lunar Exploration Target Vehicle and VV. Using the same 64-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames.

Comm-165: The Lunar Exploration Target Vehicle and VV shall use bit randomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for randomization of transmitted data streams on Rendezvous links.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the

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proper bit synchronization process and interoperability between the Lunar Exploration Target Vehicle and VV.

Comm-166: The Lunar Exploration Target Vehicle and VV shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for derandomization of received data streams on Rendezvous links.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between the Lunar Exploration Target Vehicle and VV.

Comm-167: The Lunar Exploration Target Vehicle and VV shall use NRZ-L encoding for transmission of data streams on Rendezvous links.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better E_b/N_o performance than differential symbol format encoding like NRZ-M. Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential encoding like NRZ-M.

Comm-168: The Lunar Exploration Target Vehicle and VV shall use the ASM for resolution of symbol phase ambiguity of received data streams.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like NRZ-M since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

3.2.2.3.5 DATA LINK LAYER FRAMING ON RENDEZVOUS LINK

The following section requirements are common to both Point A and Point B systems (common to both sides of the Lunar Exploration Target Vehicle–VV interface).

Comm-169: The Lunar Exploration Target Vehicle and VV shall transmit data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, September, 2015, on Rendezvous links.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between the Lunar Exploration Target Vehicle and VV.

Comm-170: The Lunar Exploration Target Vehicle and VV shall receive data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, September, 2015, on Rendezvous links.

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Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between the Lunar Exploration Target Vehicle and VV.

Comm-171: The Lunar Exploration Target Vehicle and VV shall use the Channel Access Data Unit (CADU) shown in Table 3.2.2.3-3, Channel Access Data Unit (CADU) Characteristics (Coded and Uncoded), when transmitting or receiving FEC coded or uncoded data streams on Rendezvous links.

Rationale: Required for compatibility with Orion.

The protocol stack for coded Rendezvous link is provided in Figure 3.2.2.3-1, Protocol Stack for Rate ½ LDPC Coded Links, and the protocol stack for the uncoded Rendezvous link is provided in Figure 3.2.2.3-2, Protocol Stack Option for Uncoded Links, to provide a visualization of how the data is formatted into the frames.

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TABLE 3.2.2.3-3 CHANNEL ACCESS DATA UNIT (CADU) CHARACTERISTICS (CODED AND UNCODED)

Coding	Security Mode	ASM	Transfer Frame Header	Transfer Frame Data				Frame Error Control	LDPC Code Parity Field	AOS-VCP Transfer Frame Length	AOS Code Block Frame Length	CADU Length
Rate ½ LDPC Coded	All	64 bits	48 bits	976 bits				N/A	1024 bits	1024 bits	2048 bits	2112 bits
				Security Header	M_PDU Header	M_PDU Packet Zone	Security Trailer					
	Encryption Only			64 bits	16 bits	896 bits	NA					
	Encryption + Authentication			64 bits	16 bits	832 bits	64 bits					
	Security Bypass			N/A	16 bits	960 bits	N/A					
Uncoded	All	64 bits	48 bits	1984 bits				16 bits	N/A	2048 bits	2048 bits	2112 bits
				Security Header	M_PDU Header	M_PDU Packet Zone	Security Zone					
	Encryption Only			64 bits	16 bits	1904 bits	N/A					
	Encryption + Authentication			64 bits	16 bits	1840 bits	64 bits					
	Security Bypass			N/A	16 bits	1968 bits	N/A					

Notes:

M_PDU or Encrypted M_PDU = M_PDU Header + M_PDU Packet Zone
AOS-VCP Transfer Frame = Transfer Frame Header + Transfer Frame Data + Frame Error Control (if applicable)
AOS Code Block Frame = AOS-VCP Transfer Frame + LDPC Code Parity Field
CADU Length = ASM + AOS Code Block Frame

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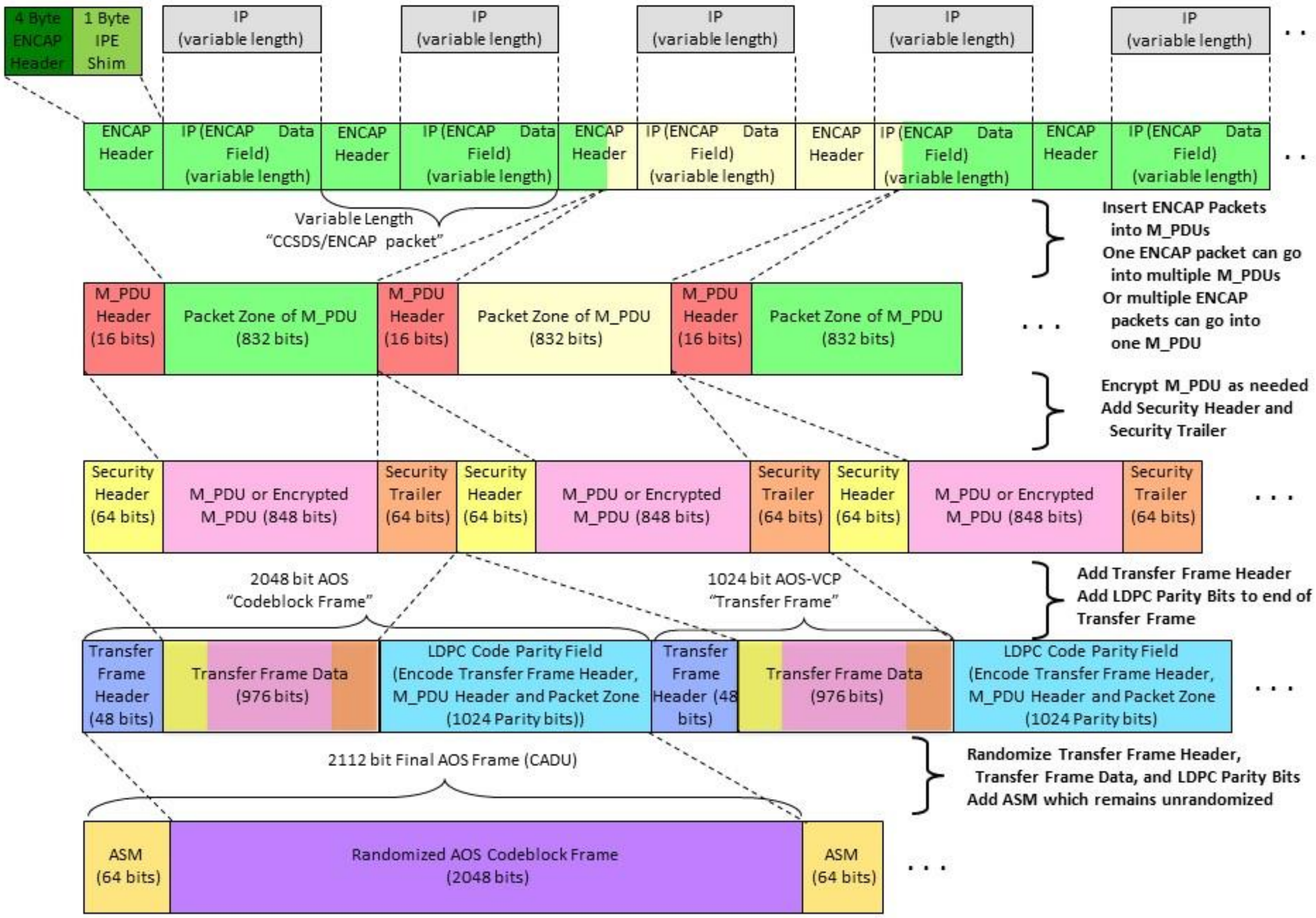

FIGURE 3.2.2.3-1 PROTOCOL STACK FOR RATE ½ LDPC CODED LINKS

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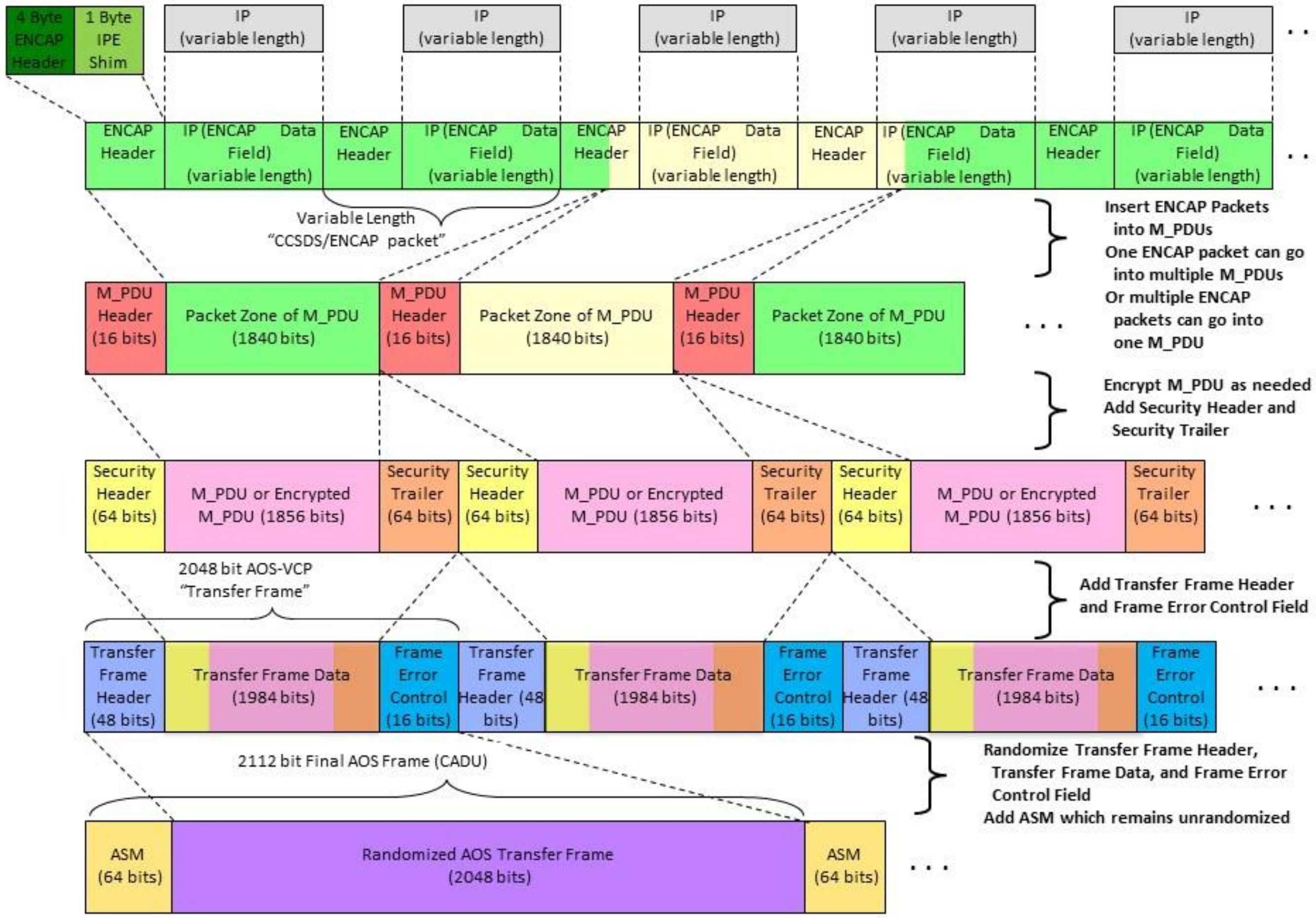

FIGURE 3.2.2.3-2 PROTOCOL STACK OPTION FOR UNCODED LINKS

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3.2.2.3.6 NETWORK AND FILE/MESSAGE LAYERS

The following section requirements are common to both Point A and Point B systems (common to both sides of the Lunar Exploration Target Vehicle–VV interface).

Comm-172: The Lunar Exploration Target Vehicle and VV shall use CCSDS File Delivery Protocol as defined in CCSDS 727.0-B-4, CCSDS File Delivery Protocol (CFDP), January 2007, on Rendezvous links.

Rationale: Provide reliable, accountable transfer of application data between the end nodes or between 2 nodes over point-to-point space link. CCSDS 727.0-B-4 is now superseded by CCSDS 727.0-B-5, but not all systems are upgrading to version 5. Any implementation of version 5 must be compatible with version 4 to guarantee interoperability. The requirement will be updated to version 5 if all systems are interoperable with version 5 by upgrading or analysis has proven that version 4 and version 5 are compatible.

Comm-173: The Lunar Exploration Target Vehicle and VV shall encapsulate IP packets as defined in CCSDS 133.1-B-2, Encapsulation Service, and CCSDS 702.1-B-1, IP Over CCSDS Space Links, on Rendezvous links.

Rationale: The CCSDS standard for transferring IP packets over a space link is to prepend CCSDS Internet Protocol Extension (IPE) octet(s) to each IP packet and encapsulate the result in a CCSDS Encapsulation packet as described in CCSDS 702.1-B-1, IP Over CCSDS Space Links, and CCSDS 133.1-B.2, Encapsulation Service. The Space Assigned Number Authority (SANA) registry lists the CCSDS recommended protocols to be encapsulated and their enumerations for the content of the IPE header.

Comm-174: DELETED

Comm-175: DELETED

Comm-176: DELETED

Comm-177: Rendezvous links should provide for the option to implement IPSec over IP links. IPSec is specified in RFC 6071, IP Security (IPSec) and Internet Key Exchange (IKE) Document Roadmap.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk when the data flows are over IP links. This requirement is recommended, not required for Orion.

Comm-178: DELETED

Comm-179: DELETED

Comm-180: DELETED

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Comm-181: DELETED

Comm-182: DELETED

Comm-183: DELETED

3.2.2.3.7 SECURITY ON RENDEZVOUS LINK

Comm-234: The Lunar Exploration Target Vehicle and VV shall be able to enable or disable encryption to support contingency operations.

Rationale: The Lunar Exploration Target Vehicle and VV need to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-184: The Lunar Exploration Target Vehicle and VV shall implement FIPS PUB 197, Advanced Encryption Standard (AES), for all encryption of inter-system data exchanges on Rendezvous links.

Rationale: AES has replaced the Digital Encryption Standard (DES) as the algorithm of choice for Federal Information Systems per FIPS PUB 197, Advanced Encryption Standard (AES). .

Comm-185: The Lunar Exploration Target Vehicle and VV shall implement the AES-GCM algorithm per NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, with 256-bit keys, 96-bit IVs, and with authentication tag lengths of 128 bits truncated to 64 bits on Rendezvous links.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-186: The Lunar Exploration Target Vehicle and VV shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, on Rendezvous links.

Rationale: Use CCSDS standards to ensure interoperability and compatibility..

3.2.2.4 LUNAR EXPLORATION SYSTEMS - EVA COMMUNICATIONS LINK

There will be Lunar Exploration System based EVAs for surface operations, and to support contingencies and/or emergencies around Lunar Exploration Systems in cislunar orbit. The current Lunar Exploration habitation systems and landing/ascent systems are being designed to accommodate a maximum of 4 EVA crew members. The Lunar Exploration System will relay the EVA data to/from Earth. When there are crewed lunar surface operations, the EVAs will be based off of the landed Lunar Exploration System, lunar rovers and/or lunar habitats. There will be up to 4 EVA crew members on the lunar surface and they communicate with the landed Lunar Exploration System or rover/habitat. The landed Lunar Exploration System or the rover/habitat will relay EVA data to/from Earth and/or an Orbiting Lunar Asset. Note: there could be

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Lunar Exploration Systems in cislunar orbit and other Lunar Exploration Systems that transition from cislunar orbit to the lunar surface and transition back from lunar surface to cislunar orbit. During EVAs around orbiting Lunar Exploration Systems, there will be 2 EVA crew members outside the Lunar Exploration System. There will be no EVAs on orbiting Lunar Exploration Systems during any rendezvous, docking, undocking, or berthing/unberthing operations.

EVAs have requirements for high-reliability, robust, low rate communications for audio, biomedical and suit telemetry (critical data) as well as for high rate data transfer for imagery, etc. (non critical data). EVAs have requirements for absolute PNT knowledge that may require support of the LunaNet LANS service as well as other navigation inputs. Any EVA PNT interfaces are specified in Section 3.2.2.9.3 if they have been identified for this interoperability specification. The current plan is for EVAs using the same communications hardware for Lunar Exploration System and other lunar surface operations.

Two different communication standards will be used to support the unique needs of EVA communications. This section will address the low rate, high reliability, robust communications between the Lunar Exploration System and EVAs (including EVA-EVA communications). The next section, 3.2.2.5, will address the non-critical, high rate communications between Lunar Exploration Systems and EVAs (including EVA-EVA communications) as well as other users and applications. An additional set of standards may be needed to support EVA navigation and these would be identified in section 3.2.2.9.3. The following communication system interoperability requirements apply to Lunar Exploration Systems both in orbit and on the lunar surface.

3.2.2.4.1 EVA COMMUNICATIONS – FREQUENCY, NUMBER OF USERS

Comm-187: Lunar Exploration Systems shall use 410 MHz – 420 MHz (Ultra-High Frequency (UHF)), frequency band to communicate with EVAs.

Rationale: UHF signal characteristics maximizes coverage around obstacles, provides immunity to fading, and provides some penetration through structures making it highly suitable to support robust, high reliability, low rate communications. (High rate communications would not be suitable at this band since it requires higher size, weight and power than other frequency bands).

Comm-188: EVAs shall use 410 MHz – 420 MHz (UHF), frequency band to communicate with Lunar Exploration Systems.

Rationale: UHF signal characteristics maximizes coverage around obstacles, provides immunity to fading, and provides some penetration through structures making it highly suitable to support robust, high reliability, low rate communications. (High rate communications would not be suitable at this band since it requires higher size, weight and power than other frequency bands).

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Comm-189: Lunar Exploration System – EVA communication system shall support simultaneous communications between up to 5 users.

Rationale: There are up to 5 users of this system at any given time (example: 4 EVAs and a Lunar Exploration System on the lunar surface; 2 EVAs, a lander, a rover and a habitat, etc.). The EVA crew members need to be able to communicate with each other and the Lunar Exploration Systems. There may be cases where surface EVA is scheduled at the same time an EVA is occurring on an orbiting Lunar Exploration System . In these situations, there is sufficient distance between the two activities that they operate as two different, independent systems and don't interfere with each other.

3.2.2.4.2 EVA COMMUNICATION LINK – SIGNAL CHARACTERISTICS

Comm-247: Lunar Exploration System – EVA Communications shall use Continuous Phase Frequency Shift Keying (CPFSK) modulation scheme.

Rationale: The EVA system is based on the ISS SSCS system which uses CPFSK modulation. This has heritage and a mature TRL.

Comm-258: Lunar Exploration System – EVA communication system shall implement a (96,80) Reed-Solomon code.

Rationale: The EVA system is based on the ISS SSCS system which uses CPFSK modulation. This has heritage and a mature TRL. The Reed-Solomon code for SSCS is specified in JSC 27528.

3.2.2.4.3 EVA COMMUNICATION LINK – NETWORK

Protocols and Standards based on some version of the ISS Time Division Multiple Access (TDMA) system are being considered for EVA communications. Once the protocols have been finalized, this section will be updated. The EVA suit health, status, biomed, audio and other telemetry/operational procedures, etc. will be exchanged on this link.

Comm-190: Lunar Exploration System – EVA communication system shall use frame and network control architecture similar to the International Space Station Space-to-Space Communication System (SSCS) as shown in Figure 3.2.2.4.3 EVA Communication Link TDMA Frame Structure.

Rationale: The ISS SSCS provides for simultaneous communications between ISS and 4 other users for ranges up to 7 kilometer (km). The system uses a TDMA architecture with 5 user slots separated by a guard band to allow for propagation delays. Any user can enter the network and establish a slot that other users synchronize to and setup their own transmissions.

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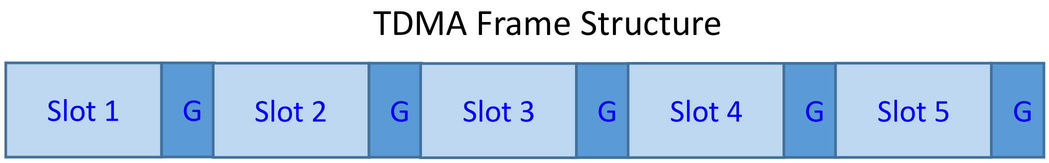

Bit Rate:	TBD kbps
Bits/Frame:	TBD
Bits/slot:	TBD
Guard Band:	TBD bits

Figure 3.2.2.4.3 EVA Communication Link TDMA Frame Structure

3.2.2.4.4 EVA COMMUNICATIONS: SECURITY

<TBD 3-3> (determining security needs and requirements/standards is forward work)

3.2.2.4.5 EVA COMMUNICATIONS: LINK PERFORMANCE

Comm-259: The Lunar Exploration System – EVA communication system shall contribute a latency to audio of no greater than 0.25 seconds including the range delay for the max range specified.

Rationale: The ISS SSCS identifies the latency required to support EVA operations.

Comm-260: The Lunar Exploration System – EVA communication system shall contribute a latency to digital data of no greater than 0.5 seconds including the range delay for the max range specified, but excluding polling delays.

Rationale: The ISS SSCS identifies the latency required to support EVA operations.

3.2.2.5 LUNAR EXPLORATION SYSTEM WIRELESS NETWORKS

This section defines the protocols and standards for wireless communications. Wireless communication networks provide communications within the Lunar Exploration System as well as communications and navigation external to the Lunar Exploration System in cislunar orbit as well as on the lunar surface. CCSDS has released a set of recommendations for wireless networking communication standards in CCSDS 883.0-B-1 and is currently working on an update to these recommendations. The LunaNet interoperability specification has leveraged those recommendations and started the discussions on using a newer release of the 3GPP standard to lower the number of 3GPP releases that are required for interoperability. There are many users and applications for wireless communications (payload data transfer, camera images, wireless sensing for monitoring, radio frequency identification (RFID) based inventory management, navigation, etc.). Wireless communications will be used to exchange

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non-critical, high rate communications between Lunar Exploration System and EVAs (including EVA-EVA communications). These wireless communication systems (3GPP) may provide a signal and messages to support EVA PNT capabilities and these would be identified within Section 3.2.2.9.3. The wireless communications between Lunar Exploration Target Vehicle and Visiting Vehicles could also be used to transfer non-critical imagery during RPOD when the Visiting Vehicle is within wireless communication range to the Lunar Exploration Target Vehicle. As mentioned previously, there would be no nominal EVAs during RPOD activities.

Standards and products for wireless communications and PNT are rapidly evolving as consumer demands call for more capability and newer technologies. Additional capabilities may be available in standards that come out when Lunar Exploration System is operational. Therefore, it is important that the wireless architecture onboard the Lunar Exploration System be flexible and upgradeable to integrate the necessary new capabilities and standards in the future.

Comm-191: Lunar Exploration System wireless systems shall use the following numerated standards for wireless communications:

1. Wi-Fi Certified 6™ or Wi-Fi Certified N™ Access point(s) for frequency ranges 2.4 – 2.48 GHz to provide wireless network extension inside and outside the Lunar Exploration Systems. Operational constraints can be used to mitigate any interference issues caused by the use of 2.4 GHz band for external wireless communications during Lunar Exploration Target Vehicle – Visiting Vehicle rendezvous, proximity operations and docking. Spectrum regulations (SFCG 32-2R3) identifies that users of the 2.4 – 2.48 GHz frequencies must provide sufficient out-of-band filtering to protect the 2483.5 – 2500 MHz lunar orbit to lunar surface RNSS band.
2. Wi-Fi Certified 6™ or Wi-Fi Certified AC™ Access point(s) for frequencies 5.150 – 5.835 GHz to provide wireless network extension inside and outside the Lunar Exploration System.
3. Access point(s) and clients conform to Wi-Fi Certified WPA2™, Wi-Fi Certified WPA3-Enterprise™ with EAP-TLS and EAP-TLSS (preferred), or Wi-Fi Certified WPA3-Personal™ to secure the Wi-Fi links between the access points and the clients. WPA2 is the minimum security level that is acceptable for the Wi-Fi links. WPA3 is desired, but there is a concern about the capabilities for some wireless clients to support WPA3 and the capability for Lunar Exploration Systems to provide the infrastructure required for Enterprise. Interoperability causes the minimum requirement to be WPA2, but systems and clients should provide the highest security posture available by using WPA3-Enterprise if possible.
4. RFID based systems shall follow the protocols and standards provided in CCSDS 881.0-M-1, Spacecraft Onboard Interface Services – RFID

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Based Inventory Management Systems, to provide RFID services within the Lunar Exploration System.

5. RFID based systems shall use the 902-928 MHz ISM band using Electronic Product Code (EPC) Global Class 1 Gen 2 (ISO 18000-6C) as given in CCSDS 881.0-M-1, Spacecraft Onboard Interface Services – RFID Based Inventory Management Systems, to provide RFID services within the Lunar Exploration System.
6. RFID based systems shall support tags conforming to **<TBD 3-6>** to provide RFID services inside the Lunar Exploration System. (Note: EPC Global Class 1 Generation 2 RFID, version 1.2.0 based on CCSDS 881.0-M-1, Spacecraft Onboard Interface Services – RFID Based Inventory Management Systems, are currently used in many systems).
7. Lunar Exploration System shall use Class II and Class III Bluetooth supporting devices conforming to Bluetooth Version 4.2, Bluetooth Classic and Bluetooth Low Energy (BLE), in the 2.4 GHz unlicensed band to provide services inside the Lunar Exploration System.
8. 3GPP systems supporting User Equipment (UE) conforming to Release 12 (and higher) in a licensed band to provide Lunar Exploration System network extension inside and outside the Lunar Exploration System. Spectrum regulations (SFCG 32-2R3) identify that users must provide sufficient out-of-band filtering to protect the 2483.5 – 2500 MHz lunar orbit to lunar surface RNSS band.

Rationale: The identified standards IEEE 802.11n/ac/ax within the Wi-Fi certified standards, Bluetooth Version 4.2, RFID support development of a wide range of non-critical application classes using durable markets for commercial off-the-shelf (COTS) hardware from a large pool of vendors and supported by sizeable development communities. Applications range from streaming high-definition video, to wearables, to passive sensors or inventory tags. IEEE 802.11ah offers substantial range extension, and is anticipated to be widely available before work on some Lunar Exploration Systems begin. 3GPP services can be deployed in licensed bands and has more evolved Quality of Service controls and therefore can be offered to critical applications. 3GPP can also provide PNT services that aren't provided by the other wireless systems. Products are available which support the wireless standards, and wired cameras or other sensors can also be integrated with wireless peripherals.

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Comm-299: EVA System wireless systems shall use the following numerated standards for wireless communications:

1. Wi-Fi Certified 6™ or Wi-Fi Certified N™ clients for frequency ranges 2.4 – 2.48 GHz interface to the Lunar Exploration System access points. Spectrum regulations (SFCG 32-2R3) identifies that users of the 2.4 – 2.48 GHz frequencies must provide sufficient out-of-band filtering to protect the 2483.5 – 2500 MHz lunar orbit to lunar surface RNSS band.
2. Wi-Fi Certified 6™ or Wi-Fi Certified AC™ clients for frequencies 5.150 – 5.835 GHz interface to the Lunar Exploration System.
3. Clients conform to Wi-Fi Certified WPA2™, Wi-Fi Certified WPA3-Enterprise™ with EAP-TLS and EAP-TLSS (preferred), or Wi-Fi Certified WPA3-Personal™ to secure the Wi-Fi links between the access points and the clients. WPA2 is the minimum security level that is acceptable for the Wi-Fi links. WPA3 is desired, but there is a concern about the capabilities for some wireless clients to support WPA3 and the capability for Lunar Exploration Systems to provide the infrastructure required for Enterprise. Interoperability causes the minimum requirement to be WPA2, but systems and clients should provide the highest security posture available by using WPA3-Enterprise if possible.
4. 3GPP User Equipment (UE) conforming to Release 12 (and higher) in a licensed band to interface with Lunar Exploration System network extension inside and outside the Lunar Exploration System. Spectrum regulations (SFCG 32-2R3) identify that users must provide sufficient out-of-band filtering to protect the 2483.5 – 2500 MHz lunar orbit to lunar surface RNSS band.

Rationale: The identified standards IEEE 802.11n/ac/ax within the Wi-Fi certified standards support development of a wide range of non-critical application classes using durable markets for commercial off-the-shelf (COTS) hardware from a large pool of vendors and supported by sizeable development communities. Applications range from streaming high-definition video, to wearables, to passive sensors. 3GPP services can be deployed in licensed bands and has more evolved Quality of Service controls and therefore can be offered to critical applications. 3GPP can also provide PNT services that aren't provided by the other wireless systems. Products are available which support the wireless standards, and wired cameras or other sensors can also be integrated with wireless peripherals.

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3.2.2.6 LUNAR EXPLORATION SYSTEM - LUNAR SYSTEM COMMUNICATION AND PNT LINKS

This section captures the standards and protocols for communications and associated PNT services between an Orbiting Lunar Asset (Gateway, LunaNet-compatible Lunar Relays) and systems in lunar orbit, lunar vicinity (example – transitioning between NHRO to Lunar surface) or on the lunar surface. The Orbiting Lunar Asset - Lunar System links will be used to communicate with lunar systems, provide associated PNT services to lunar systems, and be used to relay data between the Earth and lunar systems. In addition, the Orbiting Lunar Asset - Lunar surface links could be used to "tele-operate" lunar surface robotic systems when the Orbiting Lunar Asset has crew or robotic commanding like Gateway. Orbiting Lunar Asset – Lunar System communications will need to comply with International Telecommunication Union (ITU) recommendations for protecting the shielded zone of the moon, Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon.

Lunar surface concept of operations, mission needs, etc. are being developed by the IOAG Lunar Communications Architecture and Navigation Working Group (LCANWG), NASA and International Partners. The architecture adopted for the Orbiting Lunar Asset - Lunar Systems communications is consistent with the IOAG LCAWG's draft study recommendations, and complies with Rec. ITU-R RA.479-5. Orbiting Lunar Asset – Lunar system communications with higher forward and return data rates are critical for supporting human landing and operations on and around the lunar surface and these higher rates are provided by the Ka-band system. A fully capable S-band system on the Orbiting Lunar Asset supports the lunar system's need for radiometric tracking and data exchange with a Lunar Exploration System in Lunar orbit or Earth, thus providing communications and radiometric tracking to ascenders, descenders, etc., all the way from an Lunar Exploration Target Vehicle in Lunar orbit to the Lunar surface and back. In these scenarios, we can have Lunar Exploration Systems in Lunar orbit, Lunar Exploration Systems that are transiting to/from Orbit to the lunar surface, landed Lunar Exploration Systems and deployed Lunar Exploration Systems. The transiting, landed, and deployed Lunar Exploration Systems assume the role of "Lunar Systems" side in the following requirements and will be communicating with an orbiting Lunar Exploration System (Orbiting Lunar Asset) or Earth (Ground).

Example use case: The Gateway – HLS Conops: Gateway and HLS are both Lunar Exploration Systems. The HLS will communicate with and navigate with respect to Gateway during different mission phases, Gateway will relay HLS data to/from Earth. HLS may have a direct to/from Earth link in addition to the links with Gateway. Spectrum management will coordinate frequencies for the two systems to prevent interference, etc.:

- *Gateway is in NHRO orbit. It assumes the role of a Orbiting Lunar Asset. The HLS will come in, rendezvous and dock with Gateway. In this mission phase, HLS assume the role of "Visiting Vehicle" and will communicate with Gateway over the Gateway – VV (Rendezvous) link. The link also supports HLS navigation to Gateway.*

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- *The HLS will take crew from Gateway, undock and move away from Gateway. During this phase, Gateway is an Lunar Exploration Target Vehicle in Lunar Orbit with the role of Orbital Lunar Asset and HLS is a Lunar Exploration System again assuming a "Visiting Vehicle" role and will communicate over the Gateway-VV (Rendezvous) link. HLS navigation away from Gateway is supported by the Gateway-VV (Rendezvous) link.*
- *After HLS transits further away from Gateway (nominally a range of 400 km), it assumes the role of "Lunar System" – during transit to LLO, descent to the lunar surface, lunar surface operations, ascent and transit back to NHRO. HLS will communicate with Gateway over the Gateway - Lunar Systems (Lunar System) link.*
- *When HLS starts the RPOD activities, it is back in VV role and will communicate with Gateway over the Gateway – VV (Rendezvous) link.*

The following sections contain the recommended standards and protocols for the Orbiting Lunar Asset - Lunar Systems links, and are summarized in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links. The minimum standards are summarized in Table 3.2.2.2.6-2.

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TABLE 3.2.2.6-1 RECOMMENDED STANDARDS FOR LUNAR SYSTEM RF LINKS (PAGE 1 OF 2)

S-band Forward Link (2025-2110 MHz)[6] (Orbiting Lunar Asset to Lunar Systems)					
Symbol Rates[111]	**Modulation and Encoding[110]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 Msps ≤ symbol rate < 2 Msps	Filtered BPSK/BPSK + NRZ-L[8]	No	Code Rates ½, 4/5, 7/8, uncoded with the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the coding mode selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[7]
1 ksps ≤ symbol rate < 1 Msps	Filtered BPSK/BPSK + NRZ-L[8]	No	LDPC Code rate ½ using the following codeword size and ASM: • 256 octets plus 64 bit ASM	• 128 octets (LDPC rate ½)	
48 ksps < symbol rate ≤ 1.024 Msps	PCM/PM/Bi-phase-L[8] (modulation on residual carrier)	Yes[2]			
Symbol rate < 300 ksps	SS-BPSK CDMA[9]	Yes[9]			
0.5 ksps ≤ symbol rate ≤ 48 ksps	PCM/PSK/PM + NRZ-L[8] (modulation on subcarrier)	Yes[2]			
Ka-band Forward Link (23.15-23.55 GHz)[6] (Orbiting Lunar Asset to Lunar Systems)					
Symbol Rates[111]	**Modulation and Encoding[1, 8, 10]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 Msps ≤ symbol rate	Filtered OQPSK + NRZ-L	No	Code Rates ½, 2/3, 4/5, 7/8, uncoded with the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 3072 octets plus 64 bit ASM (for rate 2/3) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, ⅔, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[7]

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter. **Symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation**
2. CCSDS PN Ranging, Non-regenerative. Ranging chip rate: ≤ 4 Mcps per CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems, Blue Book
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
8. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (Future version 401.0 is expected to address higher PCM/PSK/PM symbol rates).
9. CCSDS 415.1-B-1 PN Ranging for CDMA Link
10. GMSK is expected to be supported by a significant number of assets in the Lunar Region. Once the capability is confirmed to be supported by a significant amount of the infrastructure, then GMSK should be added to the recommended stadnards based on the available capabilities.
11. Uncoded modes are only for contingencies and do not need to be supported over the full range of symbol rates.

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TABLE 3.2.2.6-1 RECOMMENDED STANDARDS FOR LUNAR SYSTEM RF LINKS (PAGE 2 of 2)

S-band Return Link (2200-2290 MHz)[6] (Lunar Systems to Orbiting Lunar Asset)					
Symbol Rates[111]	**Modulation and Encoding[1]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 Msps ≤ symbol rate < 2 Msps	Filtered BPSK/BPSK + NRZ-L[8]	No	Code Rates ½, 4/5, 7/8, uncoded with the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[7]
1 ksps ≤ symbol rate ≤ 1 Msps	Filtered BPSK/BPSK + NRZ-L[8]	No	LDPC Code rate ½ using the following codeword size and ASM: • 256 octets plus 64 bit ASM	128 octets (for LDPC rate ½)	
48 ksps < symbol rate ≤ 1.024 Msps	PCM/PM/Bi-phase-L[8] (modulation on residual carrier)	Yes[2]			
Symbol rate < 300 ksps	SS-BPSK CDMA[9]	Yes[9]			
0.5 ksps ≤ symbol rate ≤ 48 ksps	PCM/PSK/PM + NRZ-L[8] (modulation on subcarrier)	Yes[2]			
Ka-band Return Link (27.0 GHz – 27.5 GHz)[6] (Lunar Systems to Orbiting Lunar Asset)					
Symbol Rates[111]	**Modulation and Encoding[1, 8, 10]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 Msps ≤ symbol rate	Filtered OQPSK + NRZ-L	No	Code Rates ½, 2/3, 4/5, 7/8, uncoded with the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 3072 octets plus 64 bit ASM (for rate 2/3) • 2560 octets plus 64 bit ASM (for rate 4/5) • 1020 octets plus 32 bit ASM (for rate 7/8) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, ⅔, 4/5, or uncoded) • 892 octets (for LDPC rate 7/8)	CCSDS Space Data Link Security Protocol[7]

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter. **The symbol rates used combined with the modulation and coding have to fit within the user/mission specific spectrum allocation**
2. CCSDS PN Ranging, Non-regenerative. Ranging chip rate: ≤ 4 Mcps per CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems, Blue Book
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
8. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (Future version of 401.0 is expected to address higher PCM/PSK/PM symbol rates).
9. CCSDS 415.1-B-1 PN Ranging for CDMA Link
10. GMSK is expected to be supported by a significant number of assets in the Lunar Region. Once the capability is confirmed to be supported by a significant amount of the infrastructure, then GMSK should be added to the recommended stadnards based on the available capabilities.
11. Uncoded modes are only for contingencies and do not need to be supported over the full range of symbol rates.

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TABLE 3.2.2.6-2 MINIMUM STANDARDS FOR LUNAR SYSTEM RF LINK SERVICE PROVIDERS[10] (PAGE 1 OF 2)

S-band Forward Link (2025-2110 MHz)[6] (Orbiting Lunar Asset to Lunar Systems)					
Symbol Rates[1, 8]	**Modulation and Encoding[1, 8]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
50 ksps ≤ symbol rate < 200 ksps	Filtered BPSK/BPSK + NRZ-L	No	LDPC Code rate ½ with following codeword size and ASM: • 256 octets plus 64 bit ASM	• 128 octets (LDPC rate ½)	
50 ksps < symbol rate ≤ 100 ksps	PCM/PM/Bi-phase-L (modulation on residual carrier)	Yes[2]			
1 ksps ≤ symbol rate ≤ 10 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]			
Ka-band Forward Link (23.15-23.55 GHz)[6] (Orbiting Lunar Asset to Lunar Systems)					
Symbol Rates[1, 8,10]	**Modulation and Encoding[1, 8]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 Msps ≤ symbol rate	Filtered OQPSK + NRZ-L	No	Code Rates ½, $^2/_3$, $^4/_5$, $^7/_8$, uncoded with the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 3072 octets plus 64 bit ASM (for rate $^2/_3$) • 2560 octets plus 64 bit ASM (for rate $^4/_5$) • 1020 octets plus 32 bit ASM (for rate $^7/_8$) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, ⅔, $^4/_5$, or uncoded) • 892 octets (for LDPC rate $^7/_8$)	CCSDS Space Data Link Security Protocol[7]

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter.
2. CCSDS PN Ranging, Non-regenerative. Ranging chip rate: ≤ 4 Mcps per CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems, Blue Book
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
8. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (Future version of 401.0 is expected to address higher PCM/PSK/PM symbol rates).
9. Users of these services may select the capabilities required to implement the end-to-end interoperable link configurations needed for their mission to be ICSIS compliant.
10. Uncoded modes are only for contingencies and do not need to be supported over the full range of symbol rates.

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TABLE 3.2.2.6-2 MINIMUM STANDARDS FOR LUNAR SYSTEM RF LINK SERVICE PROVIDERS[10] (PAGE 2 of 2)

S-band Return Link (2200-2290 MHz)[6] (Lunar Systems to Orbiting Lunar Asset)					
Symbol Rates[1, 8]	**Modulation and Encoding[1, 8]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 ksps ≤ symbol rate ≤ 200 ksps	Filtered BPSK/BPSK + NRZ-L	No	LDPC Code rate ½ with following codeword size and ASM: • 256 octets plus 64 bit ASM	128 octets (for LDPC rate ½)	CCSDS Space Data Link Security Protocol[7]
50 ksps < symbol rate ≤ 100 ksps	PCM/PM/Bi-phase-L (modulation on residual carrier)	Yes[2]			
1 ksps ≤ symbol rate ≤ 10 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]			
Ka-band Return Link (27.0 GHz – 27.5 GHz)[6] (Lunar Systems to Orbiting Lunar Asset)					
Symbol Rates[1, 8, 10]	**Modulation and Encoding[1, 8]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
1 Msps ≤ symbol rate	Filtered OQPSK + NRZ-L	No	Code Rates ½, $^2/_3$, $^4/_5$, $^7/_8$, uncoded with the following codeword size and ASM is to be used: • 4096 octets plus 64 bit ASM (for rate ½) • 3072 octets plus 64 bit ASM (for rate $^2/_3$) • 2560 octets plus 64 bit ASM (for rate $^4/_5$) • 1020 octets plus 32 bit ASM (for rate $^7/_8$) • uncoded size: 2048 octets plus a 32 bit ASM	Depending on the codeword selected, the following AOS Frame size is used: • 2048 octets (for LDPC rates ½, ⅔, $^4/_5$, or uncoded) • 892 octets (for LDPC rate $^7/_8$)	CCSDS Space Data Link Security Protocol[7]

1. Symbol rate is defined at the input to the modulator or bi-phase-L converter.
2. CCSDS PN Ranging, Non-regenerative. Ranging chip rate: ≤ 4 Mcps per CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems, Blue Book
3. CCSDS 732.0-B-3 AOS Space Data Link Protocol, Blue Book
4. CCSDS 131.0-B-3 TM Synchronization and Channel Coding, Blue Book.
5. CCSDS 732.1-B-1 Unified Space Data Link Protocol, Blue Book. --- Once all the partners agree to USLP and implement it on the infrastructure side, this will become a part of the interoperability standard.
6. SFCG 32-2R2 Communication Frequency Allocations and Sharing in the Lunar Region.
7. CCSDS 355.0-B-1 Space Data Link Security Protocol, Blue Book.
8. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (Future version of 401.0 is expected to address higher PCM/PSK/PM symbol rates).
9. Users of these services may select the capabilities required to implement the end-to-end interoperable link configurations needed for their mission to be ICSIS compliant.
10. Uncoded modes are only for contingencies and do not need to be supported over the full range of symbol rates.

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3.2.2.6.1 FREQUENCY FOR LUNAR SYSTEM LINK

Ka-band and S-band are selected for the Lunar System links consistent with IOAG LCAWG draft study recommendations, and complying with ITU recommendations concerning shielded zone of the moon, Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon.

Comm-192: The Orbiting Lunar Asset shall use 23.15 – 23.55 GHz frequency band to transmit signals to the lunar system element on the Lunar System RF link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has Ka-band allocated for communications between lunar orbit and lunar surface. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-193: Lunar system element shall use 23.15 – 23.55 GHz frequency band to receive signals from the Orbiting Lunar Asset on the Lunar System RF link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has Ka-band allocated for communications between lunar orbit and lunar surface. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-194: Lunar system element shall use 27.0 – 27.5 GHz frequency band to transmit signals to the Orbiting Lunar Asset on the Lunar System link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has Ka-band allocated for communications between lunar orbit and lunar surface. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-195: The Orbiting Lunar Asset shall use 27.0 – 27.5 GHz frequency band to receive signals from the lunar system element on the Lunar System link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has Ka-band allocated for communications between lunar orbit and lunar surface. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-235: The Orbiting Lunar Asset shall use 2.025 – 2.110 GHz frequency band to transmit signals to the lunar system element on the Lunar System RF link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has S-band allocated for communications between lunar orbit and lunar surface. Having two

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frequencies meets ITU recommendations concerning shielded zone of the moon, Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-236: Lunar system element shall use 2.025 – 2.110 GHz frequency band to receive signals from the Orbiting Lunar Asset on the Lunar System RF link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has S-band allocated for communications between lunar orbit and lunar surface. Having two frequencies meets ITU recommendations concerning shielded zone of the moon, Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-237: The Orbiting Lunar Asset shall use 2.200 – 2.290 GHz frequency band to receive signals from the lunar system element on the Lunar System RF link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has S-band allocated for communications between lunar orbit and lunar surface. Having two frequencies meets ITU recommendations concerning shielded zone of the moon, Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

Comm-238: Lunar system element shall use 2.200 – 2.290 GHz frequency band to transmit signals to the Orbiting Lunar Asset on the Lunar System RF link.

Rationale: Consistent with IOAG LCAWG draft recommendations; and ITU and CCSDS/SFCG recommendations which has S-band allocated for communications between lunar orbit and lunar surface. Having two frequencies meets ITU recommendations concerning shielded zone of the moon, Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon. Systems must acquire approved spectrum allocation through the spectrum regulatory process.

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3.2.2.6.2 MODULATION FOR THE LUNAR SYSTEM LINK

The required standards for modulation on the Lunar Systems RF link are summarized in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Link, and expanded in this section. The additional recommended standards are summarized in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Link.

Comm-196: The Orbiting Lunar Asset shall implement filtered OQPSK to transmit signals to lunar system element as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System high rate, Ka-band link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between Orbiting Lunar Assets and lunar surface elements, meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

Comm-239: Lunar system element shall implement filtered OQPSK to receive signals from the Orbiting Lunar Asset as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System high rate, Ka-band link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between the Orbiting Lunar Asset and lunar surface elements, and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

Comm-240: Lunar system element shall implement filtered OQPSK to transmit signals to the Orbiting Lunar Asset as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System high rate, Ka-band link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between the Orbiting Lunar Asset and lunar system elements, and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

Comm-197: The Orbiting Lunar Asset shall implement filtered OQPSK to receive signals from lunar system element as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System high rate, Ka-band link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between the Orbiting Lunar Asset and lunar system elements, and meets spectrum constraints imposed by SFCG and NTIA, and corresponding international spectrum regulatory agencies.

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Comm-243: The Orbiting Lunar Asset shall implement filtered BPSK/BPSK for symbol rates within the ranges defined in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links, to transmit signals and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: Filtered BPSK/BPSK provides interoperability between the Orbiting Lunar Asset and lunar system elements; and meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies.

Comm-307: The Orbiting Lunar Asset should implement filtered BPSK/BPSK for symbol rates within the ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit signals and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: Filtered BPSK/BPSK provides interoperability between the Orbiting Lunar Asset and lunar system elements; and meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies.

Comm-244: Lunar system element shall implement filtered BPSK/BPSK for symbol rates within the ranges defined in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: Filtered BPSK/BPSK provides interoperability between the Orbiting Lunar Asset and lunar system elements; meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies.

Comm-300: Lunar system element should implement filtered BPSK/BPSK for symbol rates within the ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: Filtered BPSK/BPSK provides interoperability between the Orbiting Lunar Asset and lunar system elements; meets spectrum constraints imposed by SFCG, NTIA, and corresponding international spectrum regulatory agencies.

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Comm-245: The Orbiting Lunar Asset shall implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rate within the ranges defined in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links, to transmit signals and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-301: The Orbiting Lunar Asset should implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rate within the ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit signals and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-246: Lunar system element shall implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rate within the ranges defined in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-302: Lunar system element should implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rate within the ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-248: The Orbiting Lunar Asset shall implement PCM/PSK/PM with modulation on the subcarrier for symbol rate within the ranges defined in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

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Rationale: PCM/PSK/PM with modulation on the subcarrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-303: The Orbiting Lunar Asset should implement PCM/PSK/PM with modulation on the subcarrier for symbol rate within the ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PSK/PM with modulation on the subcarrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-249: Lunar system element shall implement PCM/PSK/PM with modulation on the subcarrier for symbol rate ranges defined in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PSK/PM with modulation on the subcarrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-304: Lunar system element should implement PCM/PSK/PM with modulation on the subcarrier for symbol rate ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the Lunar System low rate, S-band link.

Rationale: PCM/PSK/PM with modulation on the subcarrier provides interoperability between the Orbiting Lunar Asset and lunar system elements; supports ranging.

Comm-261: The Orbiting Lunar Asset should implement SS-BPSK CDMA for symbol rate within the ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 415.1-B-1, on the Lunar System low rate, S-band link.

Rationale: SS-BPSK CDMA modulation provides interoperability between the Orbiting Lunar Asset and lunar system elements and supports ranging. The CDMA signal allows for multiple Lunar Systems to use the same frequency.

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Comm-262: Lunar system element should implement SS-BPSK CDMA for symbol rate ranges defined in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, to transmit and receive signals as described in CCSDS 415.1-B-1, on the Lunar System low rate, S-band link.

Rationale: SS-BPSK CDMA modulation provides interoperability between the Orbiting Lunar Asset and lunar system elements and supports ranging. The CDMA signal allows for multiple Lunar Systems to use the same frequency.

3.2.2.6.3 CODING AND SYNCHRONIZATION FOR THE LUNAR SYSTEM LINK

The required standards for coding and synchronization on the Lunar Systems RF link are summarized in Table 3.2.2.6-1, Required Standards for Lunar Systems RF Link, and expanded in this section.

Comm-256: The Orbiting Lunar Asset shall be able to enable or disable forward error correction (FEC) to support contingency operations with Lunar Systems on the Lunar System link.

Rationale: The Orbiting Lunar Asset needs to be able to enable or disable FEC to support contingency and other operational scenarios. Uncoded modes are supported for lower range of symbol rates since they are used for contingency and are not used to specify or drive the performance of the Comm systems.

Comm-257: Lunar System element shall be able to enable or disable FEC to support contingency operations with the Orbiting Lunar Asset on the Lunar System link.

Rationale: Lunar System element needs to able to enable or disable FEC to support contingency and other operational scenarios. Uncoded modes are supported for lower range of symbol rates since they are used for contingency and are not used to specify or drive the performance of the Comm systems.

Comm-198: The Orbiting Lunar Asset and lunar system element shall use CCSDS Low Density Parity Check Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for encoding data as defined in , CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.6-1, Required Standards for Lunar Systems RF Links, on the Lunar System high rate Ka-band link.

Rationale: The bandwidth overhead and coding gain vary by the code selected. Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

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Comm-199: The Orbiting Lunar Asset and lunar system element shall use CCSDS Low Density Parity Check Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.6-1, Required Standards for Lunar Systems RF Links, on the Lunar System high rate Ka-band link.

Rationale: The bandwidth overhead and coding gain vary by the code selected. Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

Comm-250: For symbol rates greater than 1.024 Msps, the Orbiting Lunar Asset and lunar system element should use CCSDS Low Density Parity Check Codes, rate ½, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for encoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, on the Lunar System low rate S-band link.

Rationale: The bandwidth overhead and coding gain vary by the code selected. Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

Comm-251: For symbol rates less than or equal to 1.024 Msps, the Orbiting Lunar Asset and lunar system element shall use CCSDS LDPC rate ½ with codeword length 256 octets for encoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.6-2, Minimum Standards for Lunar Systems RF Links and Table 3.2.2.6-1 Recommended Standards for Lunar Systems RF Links, on the Lunar System low rate S-band link.

Rationale: The shorter codeword length is selected for lower data rates to reduce latency.

Comm-252: For symbol rates greater than 1.024 Msps, the Orbiting Lunar Asset and lunar system element should use CCSDS Low Density Parity Check Codes, rate ½, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.6-1, Recommended Standards for Lunar Systems RF Links, on the Lunar System low rate S-band link.

Rationale: The bandwidth overhead and coding gain vary by the code selected. Coding gain provided by LDPC codes at rate 1/2 considering a BER of 1E-6, as an example, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes.

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Comm-253: For symbol rates less than or equal to 1.024 Msps, the Orbiting Lunar Asset and lunar system element shall use CCSDS LDPC rate ½ with codeword length 256 octets for decoding data as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 7, and shown in Table 3.2.2.6-1, Required Standards for Lunar Systems RF Links and Table 3.2.2.6-1 Recommended Standards for Lunar Systems RF Links, on the Lunar System low rate S-band link.

Rationale: The shorter codeword length is selected for lower data rates to reduce latency.

Comm-200: The Orbiting Lunar Asset and lunar system element shall apply the ASM as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Lunar System link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between the Orbiting Lunar Asset and NASA/International Partner assets. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-201: The Orbiting Lunar Asset and lunar system element shall use the ASM as defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Lunar System link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between the Orbiting Lunar Asset and NASA/International Partner assets. Using the same 64-bit/32-bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.

Comm-202: The Orbiting Lunar Asset and lunar system element shall use bit randomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for randomization of transmitted data streams on the Lunar System link.

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Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between the Orbiting Lunar Asset and NASA/International Partner assets.

Comm-203: The Orbiting Lunar Asset and lunar system element shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3, TM Synchronization and Channel Coding, for derandomization of received data streams on the Lunar System link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, will ensure the proper bit synchronization process and interoperability between the Orbiting Lunar Asset and NASA/International Partner assets.

Comm-204: When using BPSK/filtered BPSK, and PCM/PSK/PM modulation schemes, the Orbiting Lunar Asset and lunar system element shall use NRZ-L encoding for transmission of data streams on the Lunar System link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better E_b/N_o performance than differential symbol format encoding like NRZ-M. Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential encoding like NRZ-M.

Comm-205: The Orbiting Lunar Asset and lunar system element shall use the ASM for resolution of symbol phase ambiguity of received data streams on the Lunar System link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like NRZ-M since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

3.2.2.6.4 RANGING FOR THE LUNAR SYSTEM LINK

Comm-242: The Orbiting Lunar Asset and lunar system element shall use non-regenerative ranging with a PN chip rate of 4 ≤ Mcps as defined in CCSDS 414.1-B-2, Pseudo-Noise (PN) Ranging Systems, on the Lunar System link.

Rationale: The Orbiting Lunar Asset and Lunar elements need to support radiometric tracking (ranging) to support GN&C. There is a Lunar Navigation Satellite System (LNSS) service identified as part of the LunaNet Interoperability Specification that may be used by Lunar Exploration Systems when it is implemented. The system can choose between radiometric measurements on the DTE link, Lunar Link, LNSS, or

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all depending on their mission needs. The non-regenerative ranging mode selected for the Lunar Link provides for simultaneous data with ranging.

Comm-305: The Orbiting Lunar Asset should implement range measurement capability as described in CCSDS 415.1-B-1, on the Lunar System low rate, S-band link.

Rationale: SS-BPSK CDMA modulation provides interoperability between the Orbiting Lunar Asset and lunar system elements and supports ranging. The CDMA signal allows for multiple Lunar Systems to use the same frequency.

Comm-306: Lunar system element should implement range measurement capability as described in CCSDS 415.1-B-1, on the Lunar System low rate, S-band link.

Rationale: SS-BPSK CDMA modulation provides interoperability between the Orbiting Lunar Asset and lunar system elements and supports ranging. The CDMA signal allows for multiple Lunar Systems to use the same frequency.

3.2.2.6.5 DATA LINK FOR THE LUNAR SYSTEM LINK

Comm-206: The Orbiting Lunar Asset and lunar system element shall transmit data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.6-1, Required Standards for Lunar Systems RF Links, on the Lunar System link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between the Orbiting Lunar Asset and NASA/International Partner assets.

Note: CCSDS recently baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

Comm-207: The Orbiting Lunar Asset and lunar system elements shall receive data streams using data link framing as defined in CCSDS 732.0-B-3, AOS Space Data Link Protocol, and shown in Table 3.2.2.6-1, Required Standards for Lunar Systems RF Links, on the Lunar System link.

Rationale: CCSDS 732.0-B-3, AOS Space Data Link Protocol, provides the structure for frame construction. Need to follow this standard to ensure interoperability between the Orbiting Lunar Asset and NASA/International Partner assets.

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Note: CCSDS recently baselined CCSDS 732.1-B-1, Unified Space Data Link Protocol. Once all partners agree to, and implement it, this standard will be updated with the CCSDS 732.1-B-1, Unified Space Data Link Protocol, Blue Book.

3.2.2.6.6 NETWORK LAYERS AND ABOVE FOR THE LUNAR SYSTEM LINK

3.2.2.6.6.1 NETWORK LAYER

Comm-208: The Orbiting Lunar Asset and lunar system element shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2, Encapsulation Service, when communicating over CCSDS Data Link Layer Protocols on the Lunar System link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-209: The Orbiting Lunar Asset and lunar system element shall transmit and receive IP packets using the CCSDS Encapsulation Service as defined in CCSDS 702.1-B-1, IP Over CCSDS Space Links, when using IP packets over CCSDS Data Link Layers on the Lunar System link.

Rationale: This allows IP packet use interoperability over CCSDS links.

Comm-210: The Orbiting Lunar Asset and lunar system element shall use IP as specified in IPv4 (RFC 791, Internet Protocol) as a network layer on the Lunar System link.

Rationale: IP provides for network layer services over interfaces that have low delay and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

3.2.2.6.6.2 TRANSPORT LAYER

Comm-211: The Orbiting Lunar Asset and lunar system element shall **<TBR 3-7>** implement LTP as specified in CCSDS 734.1-B-1, Licklider Transmission Protocol (LTP) for CCSDS, on the Lunar System link.

Rationale: LTP is a reliable point-to-point transport protocol, over which the bundle protocols will run. LTP is not expected to be used for all links, but was designed for long-haul links with high delay.

Comm-212: The Orbiting Lunar Asset and lunar element shall implement TCP as specified in RFC 793, Transmission Control Protocol, on the Lunar System link.

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Rationale: TCP is a reliable transport protocol for use on IP networks.

Comm-213: The Orbiting Lunar Asset and lunar system element shall implement UDP as specified in RFC 768, User Datagram Protocol, on the Lunar System link.

Rationale: UDP provides best effort transport protocol for use on IP networks.

3.2.2.6.6.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-214: The Orbiting Lunar Asset and lunar element shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Lunar System link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the Orbiting Lunar Asset must have the capability to multiplex/demultiplex multiple data streams from multiple sources over heterogeneous links. Bundle Protocol Version 7 has been adopted by IETF and an update of CCSDS 734.2-B-1 is in work to update to version 7. This requirement will be updated to the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7.

Comm-215: DELETED

Comm-216: The Orbiting Lunar Asset and lunar elements should provide for the option to implement IPSec over IP links. IPSec is specified in RFC 6071, IP Security (IPSec) and Internet Key Exchange (IKE) Document Roadmap.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk.

Comm-217: The Orbiting Lunar Asset and lunar element shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Lunar System link.

Rationale: In cases when bundle protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

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Comm-218: The Orbiting Lunar Asset and lunar element shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Lunar System link.

Rationale: In circumstances when bundle protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-219: The Orbiting Lunar Asset and lunar element should implement the TCP Convergence Layer Adapter as specified in RFC 7242, Delay-Tolerant Networking TCP Convergence Layer Protocol, **<TBR 3-17>** on the Lunar System link.

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242, Delay-Tolerant Networking TCP Convergence Layer Protocol, is in the experimental stage and not a finalized standard. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

Comm-220: The Orbiting Lunar Asset and lunar element should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Lunar System link.

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles. Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery. An update of CCSDS 734.2-B-1 is in work to update to Bundle Protocol version 7. This requirement will be updated to reference the new version as soon as it is published by CCSDS. Its expected that all Lunar Exploration Systems will implement Bundle Protocol Version 7 and associated Convergence Layers identified in the updated Blue Book.

3.2.2.6.6.4 APPLICATION LAYER

Comm-221: All applications transferring data over the the Orbiting Lunar Asset - lunar system element interface shall use either DTN Bundle Protocol or IP as specified above on the Lunar System link.

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Rationale: This will allow all data flows to be routable by intermediate nodes. Any application that expects to flow data to and from Earth either directly or relayed should use BP to accommodate delays or end-to-end link availability. Though IP may work in some cislunar cases, use of BP will allow the application to also function in deep space cases.

Comm-222: The Orbiting Lunar Exploration System and lunar system element shall use CCSDS File Delivery Protocol Class 1 and Class 2 as defined in CCSDS 727.0-B-4, CCSDS File Delivery Protocol (CFDP), to transmit and receive application layer files on the Lunar System link.

Rationale: CFDP provides reliable, accountable transfer of files – Class 2 is reliable, Class 1 is best effort. Class 3 and Class 4 are not required because not all Lunar Exploration partners implement these options. CCSDS 727.0-B-4 is now superseded by CCSDS 727.0-B-5, but not all systems are upgrading to version 5. Any implementation of version 5 must be compatible with version 4 to guarantee interoperability. The requirement will be updated to version 5 if all systems are interoperable with version 5 by upgrading or analysis has proven that version 4 and version 5 are compatible for Class 2 and Class 1 modes.

Comm-223: The Orbiting Lunar Exploration System and lunar system element should **<TBR 3-14>** use AMS as defined in CCSDS 735.1-B-1, Asynchronous Message Service, to transmit and receive messages on the Lunar System link.

Rationale: AMS provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient.

3.2.2.6.7 SECURITY FOR THE LUNAR SYSTEM LINK

The following define the security standards to ensure interoperability. The actual links and data to be protected, security and key management, etc. will be based on the International Partner agreement on security policies for the Program(s).

Comm-224: The Orbiting Lunar Exploration System and lunar system element shall implement CCSDS 352.0-B-1, CCSDS Cryptographic Algorithms, Advanced Encryption Standard (AES), for encryption and decryption of data exchanges on the Lunar System link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197, Advanced Encryption Standard (AES).

Comm-225: The Orbiting Lunar Exploration System and lunar system element shall implement the AES-GCM algorithm per NIST SP 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, with 256-bit keys, 96-bit IVs, with authentication tag lengths of 128-bits truncated to 64-bits for data exchanges on the Lunar System link.

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Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges. Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances.

Comm-226: The Orbiting Lunar Exploration System and lunar system element shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges on the Lunar System link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-227: The Orbiting Lunar Exploration System and lunar system elements shall implement authentication as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, for data exchanges on the Lunar System link.

Rationale: Lunar Exploration System needs to support authentication in addition to encryption.

Comm-228: The Orbiting Lunar Exploration System and lunar system elements shall be able to enable or disable encryption to support contingency operations on the Lunar System link.

Rationale: Lunar Exploration System needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-229: The Orbiting Lunar Exploration System and lunar system elements shall employ key management techniques as defined in **<TBD 3-1>** on the Lunar System link. (**<TBD 3-1>** could be Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures, as noted below).

Rationale: This requirement ensures that keys are managed in an interoperable manner.

Note: CCSDS published the CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. If all partners agree to implement it, this requirement will be updated.

3.2.2.7 EXPLORATION LUNAR SURFACE COMMUNICATIONS

It is expected that international Lunar surface campaigns will lead to the deployment of a multitude of surface vehicles (e.g., landers and rovers) and facilities for exploration and science (e.g., communications tower, telescopes, and instruments) in the various regions of the South Pole. Even for the initial landing of NASA's HLS vehicles, some rudimentary surface-to-surface communication links will exist to support crewed EVA activities on lunar surface in the vicinity of the HLS landing site, i.e., an exploration zone. At a minimum, these links include the link between the rover and lander (i.e., the Ascent Element and/or Descent Element), the link between the astronaut suit and lander/rover, and the link between the astronaut suits. Initial exploration missions are

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expecting to use a UHF-band system core critical EVA communications between the Lander/Rover/Habitat and EVAs. A brief description of this system and the standards used is given in Section 3.2.2.4 In addition, a higher rate communication link is used to send non-critical data. These links are all wireless links based on the 5 GHz band allocated to Wi-Fi communications. The wireless standards are given in Section 3.2.2.2.5 Artemis Wireless Networks. As 3GPP and other technology matures and is validated for space use, these standards are expected to be used for Lunar Surface communications and navigation. NASA, ESA, and CSA all have activities analyzing or implementing 3GPP wireless network capabilities on the lunar surface to support human exploration and science missions. These activities will contribute to what standards are supported, their spectrum allocation, what missions and capabilities they support, and when they are available for widespread use by lunar exploration systems. The ICSIS standards will be updated when these preferences are documented in IOAG reports, CCSDS 883.0 Blue Book, and the LunaNet Interoperability Specification dependent on how they apply to human exploration missions. The types of data transferred over these links for the initial HLS landings will be quite diverse varying from high-definition videos, rover status and engineering telemetry, mobility commanding information including positioning data, biomedical data, suit status and telemetry measurements, voice (including multi-channel voice), to in-suit communications display.

Beyond the HLS initial landing, more persistent surface-to-surface communications and PNT infrastructure will be built to support the various sample return missions, the series of commercial small lander missions, and the recurrent crewed surface missions including its robotic precursor missions. The following is a list of potential surface elements:

- Geophysical observatory
- Solar physics telescope
- Small science landers
- Medium-sized science landers
- Robotic survey rover
- Robotic exploration rover
- Radio telescope
- Landing beacon
- Surface communications station
- Communications tower
- Crewed rover
- Crewed landers (descent & ascent modules)
- Long duration habitats
- Cargo landers or other unmanned elements
- Surface power systems
- ISRU demonstration and pilot plants
- Lunar Master Clock
- Communications with astronauts(ascent & descent modules) on the surface during EVA

As the Lunar Exploration missions progress, the complexity and range of the surface missions will increase. The initial human explorations missions are expected to have most of the exploration activities happening within a short range of the lunar lander. Later missions will add an unpressurized rover, or Lunar Terrain Vehicle (LTV), that allows an increased range for EVAs. A pressurized rover is expected to be added later that further increases the expected range for EVAs. The short range and long range surface communications are covered separately due to this progression from short range communication in early missions to the need for longer range communications

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and PNT in following missions.

There are spectrum limitations that affect Lunar surface communications if there are EVA or HLS activities on the far side of the moon aka Shielded Zone of the moon. The 410 – 420 MHZ EVA Communication frequencies are approved for use on the Shielded Zone of the moon. The lander/rover to Earth communications will need to be relayed via an orbiting asset (S-band or Ka-band frequencies) since there is no direct line of sight to Earth from the far side of the moon.

3.2.2.7.1 SHORT RANGE LUNAR SURFACE COMMUNICATIONS

When looking at short range (hundreds of meters) communication needed within an exploration zone or human outpost, the wireless LAN (WLAN) will be provided to support the communications between the various surface elements. The WLAN forms the backbone of a Lunar Surface Network in this local area. It gives the mobile elements, e.g., the rovers, and the astronauts in EVA mode the ability to move around within the area and still be connected to the network. Through a local gateway or hub, it provides a link to the Orbiting Lunar Asset or a link to Earth. This scenario is shown in figure 3.2.2.7-1.

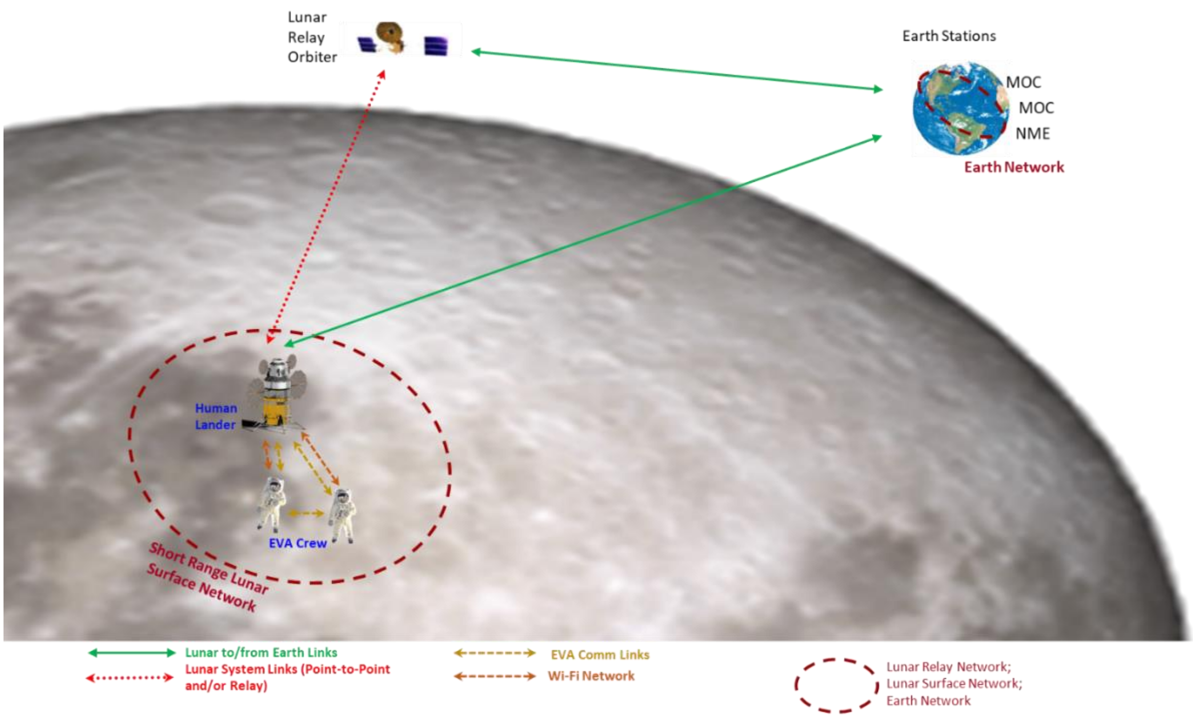

FIGURE 3.2.2.7-1 EARLY MISSION – SHORT RANGE SURFACE COMMUNICATIONS

In addition to the wireless LAN, The EVA Communication System will also support the critical communications for EVA crew within the local area.

There is the need to specify short range communication Wi-Fi standards for use by

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Lunar Exploration Systems due to the prevalence of commercially provided/owned landers and rovers potentially causing interoperability problems by allowing their use of a set of diverse proprietary communication devices. In order to help ensure interoperability, it has been determined that the Lunar Surface Network Infrastructure must be Wi-Fi alliance certified as specified in the CCSDS 883.0-B-1 Recommendations, hence an instantiation of Lunar Wi-Fi. These Wi-Fi alliance certified devices do not guarantee interoperability on the Wi-Fi infrastructure as most vendors have their own proprietary method of communicating from one access point to another. Lunar Exploration Systems need to consider this aspect of their Wi-Fi architecture during system design and potential Wi-Fi network integration with other Lunar Exploration System Access Point Providers. These Wi-Fi standards (including security specifications) are identified in section 3.2.2.5 Lunar Exporation Wireless Networks as they are applicable for Lunar Surface and Orbiting Elements.

The Wi-Fi Alliance certification offers a few advantages:

- Interoperability - They are industry standards for interoperability in wireless communications environment, specifically on the client equipment side. Wi-Fi Alliance certification provides the basis for multi-agency interoperable Wi-Fi infrastructure.
- Cost efficiency – The abundance of commercially available communication devices using these standards gives the missions a more cost-effective solution. Commercial test labs can be used for Wi-Fi Alliance certification of new Wi-Fi devices when custom implementations are required instead of the commercially available devices. One reason a custom implementation may be required is needing a more radiation tolerant device than is available commercially.
- Mobile communications – Inherent in the wireless network is its ability to support mobile surface elements.
- Expandability – As the area for the exploration zone expands, the network can be expanded by configuring/adding additional wireless access point hub.
- Security – The Wi-Fi alliance security settings protect the data traversing the Wireless Network links.

3.2.2.7.2 LONG RANGE LUNAR SURFACE COMMUNICATIONS

As the Human Exploration Missions require lunar surface communication and PNT at greater ranges, the missions will need to move to a different solution than is identified for the short-range lunar communications due to the range limitations of Wi-Fi (100’s of meters) and the UHF communications system. The ConOps for these scenarios are still being identified, but 3GPP technologies provide a favorable solution to this problem and are recommended by both CCSDS 883.0-B-1, IOAG LCAWG, and the LunaNet Interoperability Specification. These ConOps can also be satisfied by surface elements using orbital relays specified in section 3.2.2.6 for communications and PNT beyond the Wi-Fi and UHF supported distances. Its expected that programs and projects will combine short range and long range communications solutions in a fashion that meets their mission needs and dependent on any constraints or restrictions on the systems

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use (i.e. spectrum and criticality). This set of standards may need to be updated as these ConOps and technology availability further mature.

There are a couple of scenarios that could be used to support communication and PNT between Lunar Surface systems that are beyond the short range lunar communication capabilities. The first scenario is shown in Figure 3.2.2.7-2 where you have two short range lunar communication networks that are linked by an orbital relay. The figure shows that the orbital relay function between the HLS and LTV is performed by Gateway, but this relay capability could be performed by any LunaNet-compatible orbital relay satellite that supports relay between the LTV and HLS. This capability would allow longer range communication to occur between surface elements if the 3GPP solutions are not yet available for the mission. It also allows sharing of PNT observables, PNT solutions, and/or distribution of PNT services. One constraint this would place upon the mission is that it depends on the EVA crew and any other devices to be within range of HLS or LTV in order to communicate with the other local network. Another constraint may be limitations on the amount of data that can be relayed through LunaNet vs. a 3GPP solution.

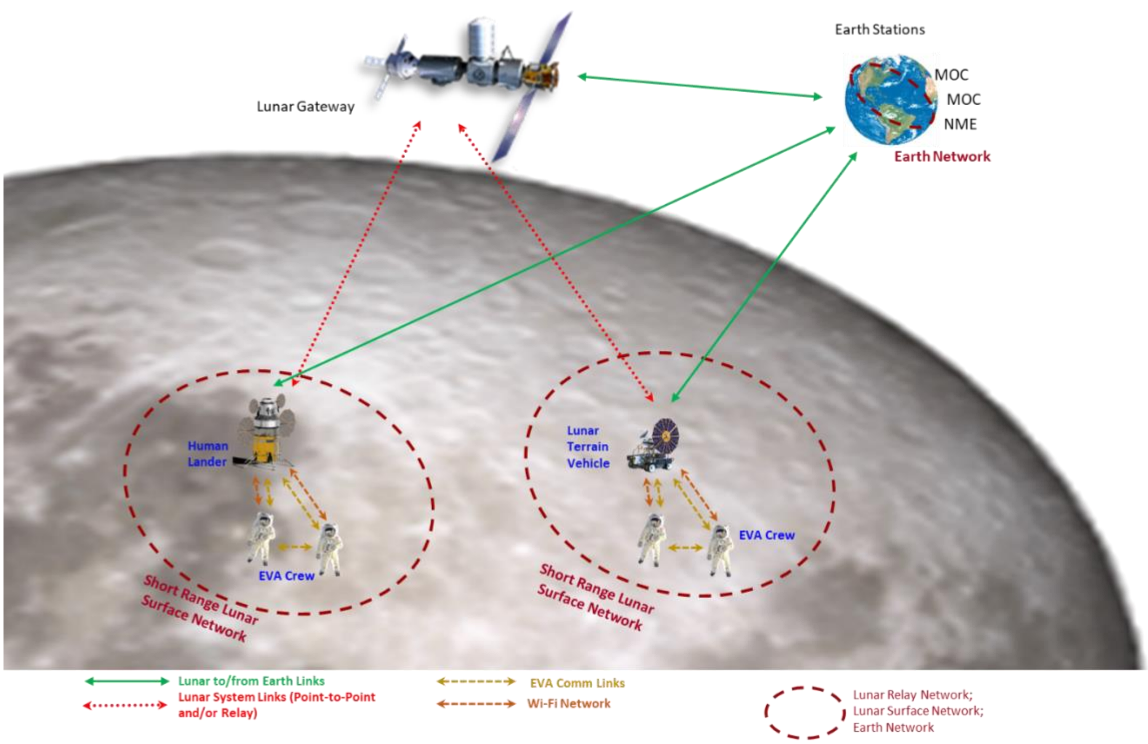

FIGURE 3.2.2.7-2 EXTENDED RANGE MISSION EXAMPLE

A second scenario would be when systems implement the 3GPP standard identified in 3.2.2.5 Lunar Exporation Wireless Networks. In this case, the architecture can now support surface communication with a range of roughly 10 km, and 3GPP-based PNT when triangulation among 3GPP towers is available. Use of this 3GPP technology doesn’t preclude the use of orbital relays shown in the previous scenario but provides additional capabilities. In this scenario, it shows the multiple short range Lunar Surface

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Networks that support the Wi-Fi and EVA capabilities identified in this section that surround the HLS, LTV, and Pressurized Rover. There are then two methods that can connect the Pressurized Rover and HLS. The systems can use an orbital relay and/or the 3GPP specified capabilities for long-range surface communication and PNT. The two systems can provide complementary capabilities for PNT. This scenario shows the 3GPP capabilities within the surface elements in Figure 3.2.2.7-3, but the capability could be added as a crew system capability. Depending on the implementation, the 3GPP solution could replace the UHF EVA Communication capability if its certified for critical operations and the Wi-Fi capability. It is also notable that 3GPP is currently working to standardize “Non-terrestrial Networking” (NTN) solutions that distribute a portion of the 3GPP network architecture on a satellite platform, and to advance the standards to improve the PNT capabilities of the network. NTN may provide a fruitful migration path for integrating surface 3GPP networks with LunaNet over time.

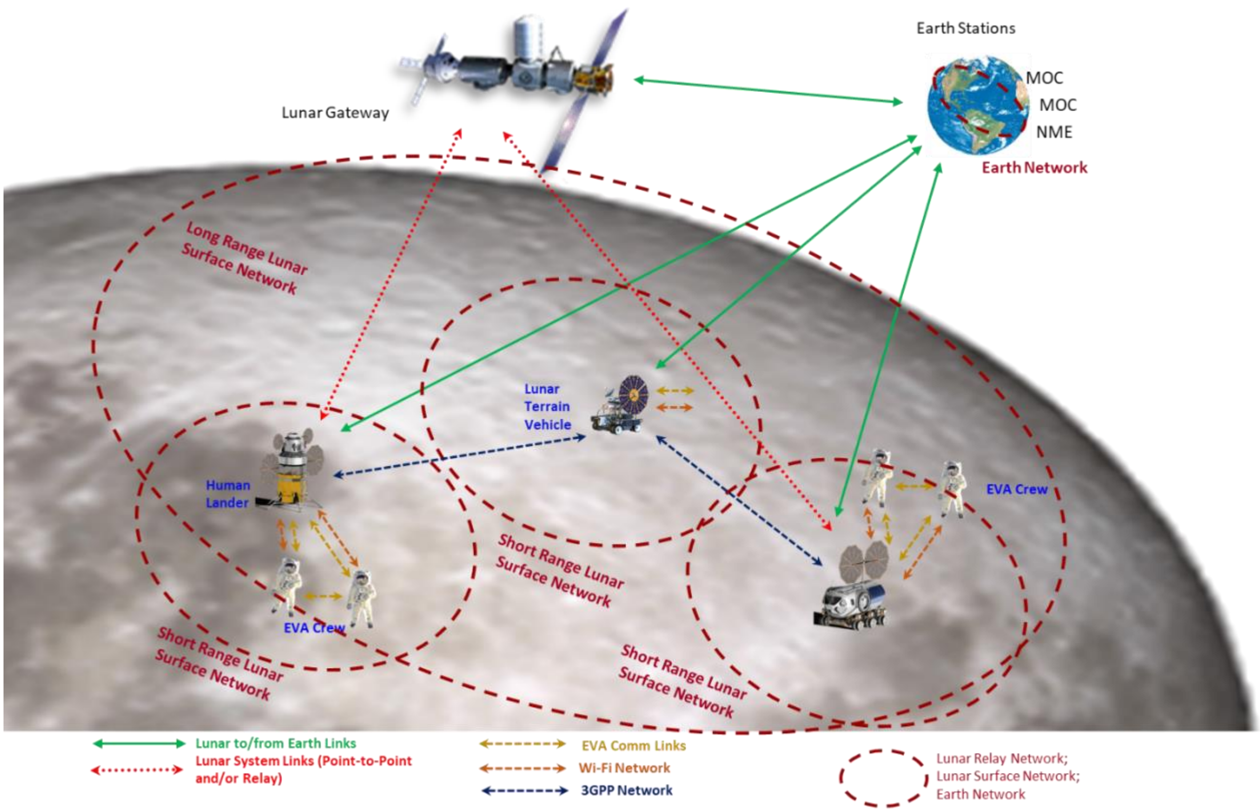

FIGURE 3.2.2.7-3 LONG RANGE SURFACE COMMUNICATIONS EXAMPLE

3.2.2.8 LUNAR SEARCH AND RESCUE (LUNASAR)

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

LunaSAR services include location reporting of distress information, and bi-directional messaging between LunaSAR beacon users and message. The LunaSAR capabilities

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are distributed between an UHF capability that provides one-way distress indication services similar to terrestrial Cospas-Sarsat services and an S-band capability that is specified within the LunaNet Interoperability Specification for bi-directional distress messaging.

The LunaSAR capabilities are not expected for early Lunar Exploration missions, but the mission effectivity will be defined as the Lunar Exploration concept of operations is matured for the later missions.

3.2.2.8.1 LUNASAR UHF COMMUNICATIONS LINK

The Lunar Search and Rescue (LunaSAR) UHF Communications Link is a one-to-many link for conveyance of distress information for lunar surface users including EVA crewmembers, human mobility systems, crewed lunar habitation locations and fixed site elements of importance to crew safety (i.e., life-critical surface power locations). LunaSAR UHF Communications Link transmissions only occur during life-critical events and emergencies on a dedicated 406 MHz (UHF) frequency band interoperable with future LunaNet Interoperability Specification-compliant space assets. LunaSAR also transmits on a specific S-Band frequency to a lunar relay orbiter. Section 3.2.2.8.1 only covers the UHF Communications Link element of the LunaSAR distress notification architecture.

The LunaSAR UHF Communications link operates one-way from users-in-distress to localized rescue assets and future orbiting UHF LunaSAR receivers in a detection/notification architecture modelled after the terrestrial International Cospas-Sarsat Programme used to save lives on Earth. The LunaSAR UHF Communications link is the surface-to-surface and UHF-only-surface-to-orbit element of the larger LunaSAR architecture to allow for early on-ramping of capability within planned spectrum and hardware developments. The LunaSAR waveform is based on CCSDS and LunaNet interoperability standards to allow for streamlined integration between the UHF and the S-band elements of the integrated LunaSAR architecture involving future LunaNet-compatible orbiting comm/PNT relays.

For surface rescue communications, an element in distress (such as an individual EVA crew member or damaged human surface mobility platform) will transmit dedicated distress messages on the 406.0-406.1 MHz frequency band detailing information such as beacon ID, location information, and rotating fields allowing for customized messaging with further details on distress event causes and user status. Localized (within 2.5 km) surface receivers will detect and decode distress messages, allowing for effective coordination and relay of emergency information for a specific lunar search and rescue incident. This is analogous to current terrestrial search and rescue coordination principles, adapted to the lunar surface extreme environment.
Example lunar surface rescue elements include lunar surface rovers with compatible 406 MHz receiver equipment, partner astronauts with dedicated 406 MHz LunaSAR receivers, and fixed-location LunaSAR detectors, among other future hardware solutions.

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TABLE 3.2.2.8-1 - LUNASAR UHF COMMUNICATIONS FORWARD LINK CHARACTERISTICS

LunaSAR UHF Communications Forward Link (406.00 – 406.10 MHz) (User-In-Distress to Rescuer / Repeater)					
Symbol Rate	Modulation & Encoding	Ranging	Coding	CCSDS Standards	Space Data Link Security
1000 bps	SS-BPSK CDMA	N	Custom LDPC R=1/2	732.0-B-4	N/A **<TBR 3-31>**

3.2.2.8.1.1 LUNASAR UHF COMMUNICATIONS – FREQUENCY, NUMBER OF USERS

Comm-263: LunaSAR UHF Communications Link beacons/emitters shall use 406.0 – 406.1 MHz (Ultra-High Frequency (UHF)), frequency band to communicate with LunaSAR surface receivers.

Rationale: UHF signal characteristics maximizes coverage around obstacles, provides immunity to fading, and provides some penetration through structures making it highly suitable to support robust, high reliability, low-rate communications. Surface receivers include surface data relays, rovers, and other surface elements. 406 MHz currently used for terrestrial search and rescue (SAR) applications, allowing for lower-cost emitter and receiver development.

Comm-264: LunaSAR UHF Communications Link beacons/emitters shall use 406.00 – 406.1 MHz (Ultra-High Frequency (UHF)), frequency band to communicate with LunaSAR-dedicated lunar orbiting repeaters/receivers <TBR 3-35>.

Rationale: UHF signal characteristics maximizes coverage around obstacles, provides immunity to fading, and provides some penetration through structures making it highly suitable to support robust, high reliability, low rate communications. (High-rate communications would not be suitable at this band due to very limited spectrum allocation).

Comm-265: LunaSAR UHF Communications Link beacons/emitters shall operate using circular (RHCP) or linear antenna polarization.

Rationale: Allows for leveraging of existing state-of-the-art terrestrial distress beacon systems for lunar use.

Comm-266: LunaSAR UHF Communications Link beacons/emitters shall operate at 406.05 MHz frequency center-band.

Rationale: 406.05 MHz center frequency is used for terrestrial search and rescue (SAR) emitters, and allows for adequate bandwidth allocation taking into consideration lunar radio astronomy protection.

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Comm-267: LunaSAR UHF Communications Link systems shall support simultaneous one-way communications between a minimum of 35 emitters and associated receiver(s) **<TBR 3-32>**.

Rationale: Current architectures include multiple EVAs, lunar surface elements and habitats, driving need for multiple user access in the event of a large-scale SAR event (such as multiple EVA crew member injury in parallel with rover emergency). Earth-based International Cospas-Sarsat Programme satellite-aided search and rescue systems support 100+ users of SAR services simultaneously, with performance characteristics to be replicated in lunar use. LunaSAR users/emitters need to be able to transmit distress data in the event of a wide-area event, e.g., solar weather events, or widespread hardware failures. For example, if a major solar event occurs while the crew is on the surface, rescue forces will want to know the potential emergency status of all the assets/crew within the same time period

Comm-268: LunaSAR Surface UHF Communication Links shall operate at a maximum range of 2.5 km **<TBR 3-33>**

Rationale: This range represents the EVA walkback distance plus safety margin, and range sizing parameter for combined beacon transmit power and receiver performance. This walkback is assuming nominal walkback to HLS, LTV, or Pressurized Rover for the localized UHF link. LunaSAR support for a 10 km contingency walkback from Pressurized Rover would come from Orbiting assets and not this localized surface link.

3.2.2.8.1.2 LUNASAR UHF COMMUNICATIONS LINK – SIGNAL CHACTERISTICS

Comm-269: LunaSAR UHF Communications Link beacons/emitters shall use a Bi-Phase Shift Key (BPSK) modulation scheme for distress transmissions.

Rationale: BPSK is a robust modulation that is well suited for low-rate data links. Higher order modulations (e.g., QPSK, 8PSK) require higher transmit power to achieve the same probability of successful message reception. LunaSAR emitters are planned to be interoperable with future LunaNet-compatible relay systems using S-band link. Use of BPSK in UHF links allows for software simplicity and replication of distress message in both UHF and future S-band.

Comm-270: LunarSAR UHF Communications Link beacon/emitter data rate shall be 500 bps, and the symbol rate shall be 1000 bps.

Rationale: A full LunaSAR burst is approximately 1065 bits, resulting in on-air time of ~1 s.

Comm-271: LunaSAR UHF Communications Link beacons/emitters shall use direct sequence spread spectrum (DSSS) for code division multiple access (CDMA). Note: The spreading code is defined in CCSDS 415.1-B-1 **<TBR 3-36>**. The code is generated using a Gold Code as defined in section 5.3

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in that standard. Each BPSK symbol is spread into 64 chips, resulting in a chip rate of 64,000 chips/s. The user-unique initial condition is set by the 12 LSBs of the beacon ID. Note that only the I-channel branch is used.

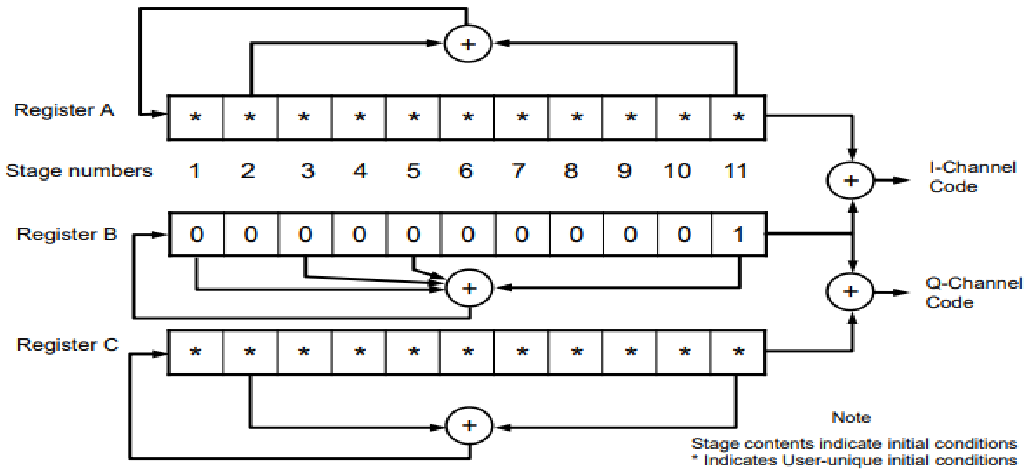

FIGURE 3.2.2.8-1 PN CODE GENERATION PER FIGURE 5-2 IN CCSDS 415.1-B-1

Rationale: LunaSAR must be able to support multiple simultaneous users in a narrow spectrum allocation. The users cannot be assumed to be synchronized in time, making a time division multiple access (TDMA) approach impractical. Given the very low data rates required for LunaSAR, DSSS provides a simple solution to multiple access. DSSS is additionally desirable as it increases the effective signal bandwidth to facilitate localization from orbiting assets. The assignment of the beacon ID must be coordinated between the users to ensure that users do not interfere with each other by using same spreading code.

Comm-272: LunarSAR UHF Communications Link beacon/emitter signal shall be pulse shaped using a root-raised-cosine (RRC) filter with a rolloff of 0.35.

Rationale: Pulse shaping constrains the signal bandwidth to the allocated bandwidth of 406.0 to 406.1 MHz.

3.2.2.8.1.3 LUNASAR UHF COMMUNICATIONS LINK – EMITTER TRANSMISSION SCHEDULE AND TIME

Comm-273: LunaSAR UHF Communications link emitters/beacons shall have a 1065 ms ±1 ms transmission time of each burst, measured at the 90 percent power points.

Rationale: Identical transmission time to allow for use of current SAR signal detection technology and architectures for lunar surface SAR use and maintain potential for future lunar orbit 406 MHz repeater systems. 1065 ms transmit time limits impacts to radio astronomy as well as serves to conserve emitter battery power.

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Comm-274: LunaSAR UHF Communications Links emitters/beacons shall transmit with the following transmission schedule following activation **<TBR 3-34>**:

TABLE 3.2.2.8-2 - LUNASAR UHF COMMUNICATIONS TRANSMISSION SCHEDULE

LunaSAR Phase	Time from Activation	Transmission Repetition Interval	Randomization
Initial Notification / Independent Location	0 – 60 seconds	5 seconds	0,1,2,3,4 s
Notification	1-30 minutes	30 seconds	± 5 Seconds
Sustained Notification	30 minutes +	60 seconds	± 5 Seconds

Rationale: "Front-loading" transmission schedule allows for more effective independent localization with future systems utilizing FDOA/TDOA trilateration processes, as well as ensuring data is received by rescue forces early in a search and rescue event. Repetition interval is increased over time to conserve emitter power, while still providing near-real-time distress status. Randomization of transmission start reduces probability of multiple users stepping on each other. The CDMA waveform selected for LunaSAR provides a way to separate multiple simultaneous users but performance will begin to degrade with more than 16 simultaneous users (1/4 of the number of chips per symbol). Assuming uniformly distributed random offset over the 5 s repetition interval with 1 s transmit duration, only 1/5 of the users (35 / 5 = 7) will be transmitting simultaneously.

3.2.2.8.1.4 LUNASAR UHF COMMUNICATION LINK: DISTRESS MESSAGE CONTENTS

The detailed contents of the LunaSAR message are in development via consultation with Extravehicular activity and Human Surface Mobility (EVA & HSM) communities. The data fields described in this section represent a first pass indicative of the types of data that can be formatted into distress messages, including vehicle telemetry from rovers or other human mobility system. The receivers and transmitters will be designed to allow easy modification of the message contents, within the constraints of maximum message payload size.

Comm-275: LunaSAR UHF Communications Link emitters/beacons shall transmit distress message payloads as defined in LunaNet Interoperability Specification Appendix AD7 **<TBR 3-37>**.

3.2.2.8.1.5 LUNASAR UHF COMMUNICATION LINK: DISTRESS MESSAGE BURST STRUCTURE

This section details the requirements for distress emitter/beacon message structuring to maintain CCSDS compatibility to the maximum extent possible, alignment with planned and evolving LunaNet message structures, and encoding using Concise Binary Object Representation (CBOR) to create a self-describing format where the data type of each

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field is specified explicitly. The LunaSAR message payload goes through multiple levels of wrapping to achieve CCSDS compatibility, as delineated in the below requirements.

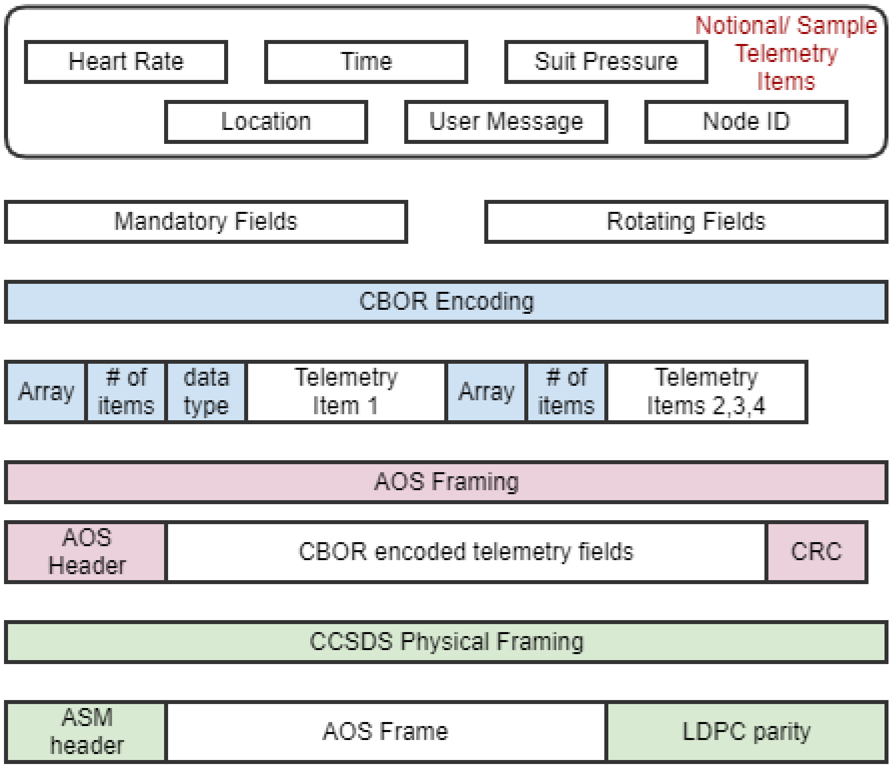

FIGURE 3.2.2.8-2 – DISTRESS BURST MESSAGE STRUCTURE

Comm-276: LunaSAR Communication Link emitters / beacons shall encode raw telemetry fields in message payloads using Concise Binary Object Representation (CBOR) for distress message bursts.

Rationale: CBOR increases potential message size is balanced by simpler integration and reduced probability of misinterpreting message contents.

Comm-277: LunaSAR Communication Link emitters / beacons shall include CCSDS AOS framing in the LunaSAR CBOR encoded message for distress message bursts.

Rationale: AOS provides combability with the LunaNet infrastructure and facilitates routing of the packets.

Comm-278: LunaSAR Communication Link emitters / beacons shall include CCSDS physical layer framing consisting of custom Rate 1/2 LunaSAR LDPC encoding and addition of a fixed preamble (ASM) for distress message bursts.

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Frame before discarding the padded zeros

64-bit word																									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
ASM (8)	AOC Frame								zeros (not TX)								LDPC parity								

Actual over-the-air frame

64-bit word																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ASM (8)	AOC Frame								LDPC parity							

ASM: 0000001101000111011110110110001110010011100101000100101011011 0000

FIGURE 3.2.2.8-4 LUNASAR PHYSICAL LAYER FRAME

Rationale: LunaSAR Communication Link emitters / beacons channel code LunaSAR frames using a slightly modified LDPC code from CCSDS 131.0-B-3. The LunaSAR message is approximately 512 bits, which is smaller than the smallest LDPC code block defined in the standard. The message is padded by 512 zeros to 1024 b block size, and then encoded using the rate 2/3 code to 1536 b. The inserted zeros are dropped, resulting in a 1024 b code block. Note that the zeros are inserted at the receiver before decoding. The resultant code rate is ½, and the performance is very close to that of the rate ½ code specified in the standard.

3.2.2.8.1.6 LUNASAR UHF COMMUNICATION LINK: LUNASAR SURFACE UHF RECEIVER CHARACTERISTICS

LunaSAR Surface UHF Receiver Characteristics are under development, based on evolving operational analysis and RF characterization.

Comm-279: LunaSAR Surface UHF Communication Link Receivers/Repeaters shall have an receive frequency range of 406.0 to 406.1 MHz

Comm-280: LunaSAR Surface UHF Communication Link Receivers/Repeaters shall have a Receive Antenna Polarization of circular (RHCP).

Comm-281: LunaSAR Surface UHF Communication Link Receivers/Repeaters shall include CCSDS physical layer de-framing consisting of custom rate 1/2 LunaSAR LDPC decoding and removal of a fixed preamble (ASM) for distress message bursts.

Rationale: LunaSAR Communication Link emitters / beacons channel code LunaSAR frames using a slightly modified LDPC code from CCSDS 131.0-B-3. The LunaSAR message is approximately 512 bits, which is smaller than the smallest LDPC code block defined in the standard. The message is padded by 512 zeros to 1024 b block size, and then encoded using the rate 2/3 code to 1536 b. The inserted zeros are dropped,

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resulting in a 1024 b code block. The zeros are inserted at the receiver before decoding. The resultant code rate is ½, and the performance is very close to that of the rate ½ code specified in the standard.

3.2.2.8.1.7 LUNASAR UHF COMMUNICATION LINK: LUNASAR ORBITAL UHF RECEIVER CHARACTERISTICS <TBR 3-35>

The LunaSAR Orbital UHF Receiver is a notional UHF -band receiver/repeater element allowing for UHF message detection and RF localization from lunar orbitCharacteristic listing derived from Cospas-Sarsat document C/S T.016 – Issue 1 – Rev. 5 *Description of the Payloads used in the Cospas-Sarsat MEOSAR System*, table 3.1.6.1 *DASS S-Band SAR Receiver Parameters.*

Comm-282: LunaSAR Orbital UHF Communication Link Receivers/Repeaters shall have an uplink frequency range of 406.0 to 406.1 MHz.

Comm-283: LunaSAR Orbital UHF Communication Link Receivers/Repeaters shall have a Receive Antenna Polarization of circular (RHCP).

Comm-284: LunaSAR Orbital UHF Communication Link Receivers/Repeaters shall include CCSDS physical layer de-framing consisting of custom Rate 1/2 LunaSAR LDPC decoding and removal of a fixed preamble (ASM) for distress message bursts.

Rationale: LunaSAR Communication Link emitters / beacons channel code LunaSAR frames using a slightly modified LDPC code from CCSDS 131.0-B-3. The LunaSAR message is approximately 512 bits, which is smaller than the smallest LDPC code block defined in the standard. The message is padded by 512 zeros to 1024 b block size, and then encoded using the rate 2/3 code to 1536 b. The inserted zeros are dropped, resulting in a 1024 b code block. The zeros are inserted at the receiver before decoding. The resultant code rate is ½, and the performance is very close to that of the rate ½ code specified in the standard.

3.2.2.8.1.8 LUNASAR UHF COMMUNICATION LINK – NETWORK

Reserved for discussion on integrating LunaSAR into LunaNet, i.e. placeholding capability to ingest lunar PNT and repackage into LunaSAR distress message.

3.2.2.8.1.9 LUNASAR UHF COMMUNICATION LINK: USAGE CONSTRAINTS

Comm-285: LunaSAR UHF Communications Links shall only be active during emergency operations involving life-safety-critical events.

Rationale: Emergency use mirrors terrestrial Cospas-Sarsat Programme architecture and serves to preserve spectrum allocations for distress notifications/transmissions. Emergency-use-only operations additionally serves to protect radio astronomy investigations.

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3.2.2.8.1.10 LUNASAR UHF COMMUNICATION LINK: SECURITY

Comm-286: LunaSAR UHF Communications Link shall support transmission of user-encrypted information if desired by LunaSAR distress beacon user.

Rationale: Encryption may be required in future iterations of LunaSAR use, for example, for passing biomedical data over a LunaSAR UHF Communications Link. The requirement is meant to enable user-side encryption, but not necessarily mandate encryption of the LunaSAR link itself.

3.2.2.8.2 LUNASAR S-BAND COMMUNICATIONS LINK

< Reserved – Summary description in LunaNet Interoperability Specification (Section 3.3.1) >

3.2.2.9 LUNAR POSITION, NAVIGATION, AND TIMING

Lunar Exploration Systems require Position, Navigation, and Timing (PNT) Services to support their mission objectives. These PNT services are largely taken for granted on Earth and in Near Earth Orbit due to the abundance of Global Navigation Satellite System (GNSS) satellites, but cislunar space missions must identify how they will satisfy their PNT needs since a similar system does not yet exist in cislunar space. Another issue with Lunar PNT services is that there is currently a lack of PNT standards in the Lunar region other than the guidance provided in the International Rendezvous System Interoperability Standards (IRSIS). This only defines standards for the rendezvous operations. There are other Lunar Exploration System needs that are not covered by IRSIS, such as the need for Lunar Exploration Systems to land within 50 radial meters of their designated landing target. Lunar Exploration PNT needs are continuing to be identified and identify position knowledge at values much better than 50 meters. Lunar Exploration Systems can use the Radiometric Services that are provided by Earth ground stations for navigation support.

These services are well-defined and have been used for Deep Space Missions. Examples of these services can be seen in the Deep Space Network (DSN) Handbook and in CCSDS 414.1-B-2. These services require Earth-based measurements and are not currently suitable for in-situ, autonomous, near-real-time operations. The LunaNet Interoperability Specification (Section 3.2) has identified a set of PNT services to be provided by LunaNet compatible satellites in cislunar space. As part of these services, there would be support for a number of PNT services that would take place over point-to-point links similar to what transpires for the Earth-based radiometric services. LunaNet also identifies an Lunar Navigation Satellite System capability similar to GNSS that provides a ubiquitous set of signals in space to aid kinematic and dynamic position, velocity, and time solutions. As part of the LunaNet PNT Interoperability development, there will be other standards generated for the LunaNet and User Signal Structure definition, LunaNet measurement schema and parameters, LunaNet detailed message definition, LunaNet Location services for users, Lunar Reference Frame Standard, and Lunar Time System Standard. Another known capability for navigation support is the

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use of weak-signal GNSS to take advantage of the existing GNSS signals in the Lunar region. Only a minimum set of these capabilities are identified as part of ICSIS to define a minimal interoperability capability. Lunar Exploration Systems will need to determine the capabilities identified that support their mission needs.

3.2.2.9.1 LUNAR POSITION, NAVIGATION, AND TIMING STANDARDS

This section is a placeholder for standards that are fundamental to PNT once they are agreed to by all International Partners.

3.2.2.9.2 EARTH-BASED POSITION, NAVIGATION, AND TIMING SUPPORT

Lunar Exploration System standards for the X-band Telemetry, Tracking, and Command Link (Section 3.2.2.2.1.4) identify the use of CCSDS 414.1-B-2 ranging to obtain radiometric range and radiometric Doppler measurements from the Earth Ground Stations. These radiometric measurements are used for state determination and orbit determination.

There currently is not an ICSIS specified standard for time synchronization from Earth. Orion and Gateway are both expected to use the Return Data Delay method to correlate their spacecraft time with Mission Control Center – Houston (MCC-H) and then have MCC-H provide commands to work toward correcting for the time error. Any global PNT requirements or standards will be identified in Section 3.2.2.9.1 and specific requirements for this Earth-based interface will be contained in this section.

3.2.2.9.3 POSITION, NAVIGATION, AND TIMING SUPPORT DURING RENDEZVOUS

Lunar Exploration System standards for the S-band Rendezvous Link (Section 3.2.2.3.2) specify a set of signal types that support radiometric measurements with PN ranging as identified in CCSDS 415.0-B-1. These radiometric measurements provide the range and Doppler estimates between the chase and target vehicle during rendezvous, proximity operations, and docking (RPOD). The details of the transfer of position, navigation, and timing information is identified in IRSIS.

3.2.2.9.4 CISLUNAR-BASED POSITION, NAVIGATION, AND TIMING SUPPORT

Lunar Exploration System standards for the S-band Lunar System Link (Section 3.2.2.2.1.4) identify the use of two types of ranging to obtain radiometric range and radiometric Doppler measurements from Lunar Orbiting Systems. These Lunar orbiting systems could be LunaNet compatible satellites or Gateway. These radiometric measurements are used for position, velocity, and time determination. LunaNet is working to identify the messages required to provide the Lunar System using the service with the information required to support that lunar system's navigation.
The required ranging specification for CCSDS 414.1-B-2 ranging on the S-band Lunar System Link was identified for two reasons. The first is that the link can support radiometrics and data transfer simultaneously. A second reason is that the standard is the same as that defined for the X-band Earth Communication Link. This allows a

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similar transponder capability to be shared for both the links as the processing is similar that can be adjusted for the different frequency bands.

The recommended ranging specification for CCSDS 415.1-B-1 ranging on the S-band Lunar System Link was identified when it was included in the LunaNet Interoperation Specification. This standard supports radiometrics and data transfer simultaneously. This capability provides a similar transponder capability to the ranging used for the Rendezvous link.

The LunaNet Interoperability specification (Section 3.2.2) identifies a lunar navigation satellite service (LNSS) called Lunar Augmented Navigation System (LANS) that provides position, navigation, and timing services similar to GPS on Earth in a one-to-many and many-to-one manner. LANS consists of multiple spatially separated relays transmitting the Augmented Forward Signal (AFS) with the specialized signal structure and messaging needed for accurate PNT. This provides an alternative means to the radiometrics on Earth links or Lunar System Links for information to use for autonomous navigation. This will allow users to compute their position, velocity, and time offset from the reference clock from the received RF signal, the associated messages, and the known characteristics of the LunaNet nodes.

Although LANS forms the backbone of the lunar PNT service, planned lunar activities may demand other sensor input to inform a relative position and navigation solution. Techniques such as Optical Navigation using photographic or LiDAR-based imagery, Inertial Measurement Units for orientation and state prediction, and traverse metrics (odometry) are all useful measurements to inform a robust navigation solution. These can be useful in scenarios where RF signals are blocked (e.g. caves) or when a relative state needs enhanced local data (e.g. rover parking next to dropped cargo for retrieval).

Comm-287: Lunar Exploration Systems shall use 2483.5 – 2500 MHz (S-band) frequency band, with a center frequency at 2492.028 MHz, to receive LunaNet LANS signals from orbiting Lunar Elements.

Rationale: SFCG has approved the use of this frequency band for LNSS signals from Lunar Orbit to Lunar Surface via broadcasts. The LunaNet Interoperability Specification has identified this as a LunaNet provided PNT service.

Comm-288: Lunar Exploration Systems shall use LunaNet LANS signals from orbiting Lunar Elements to autonomously compute its position, velocity, and time offset from the LunaNet reference time as specified by the LunaNet Interoperability Specification (Section 3.2.2).

Rationale: LANS provides capabilities similar to those provided by Earth's GPS satellites. The specification of this service and the implementation

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details are being specified within the LunaNet Interoperability Specification and associated documents.

Comm-289: Lunar Exploration Systems shall use LunaNet specified messages to exchange information required for position, navigation, and timing services as specified by the LunaNet Interoperability Specification (Section 3.2).

Rationale: LunaNet messages are being specified to exchange the information that is required to support Lunar Exploration System position knowledge, navigation, and time error.

3.3 PERFORMANCE

The link specific performance parameters and requirements (example: data rates, bit-error rates, received power, antenna gain, etc.) will be captured in the Interface Control Documents (ICD)s between the respective end points. The standards required for interoperability are defined in this version of the document (provides the necessary requirements for interoperability). The next version of the document may include the details at specific protocol stack levels and meeting them will be sufficient for interoperability – in the course of defining those details, if there is a need to specify data rates (or any other parameter) as part of the protocol stack, it will be added to this document.

For reference, anticipated data rates for the different links and a basis of estimation for these data rates is given in Appendix F.

Comm-230: All Lunar Exploration System communication links should have a minimum 3 dB link margin.

Rationale: Having a certain amount of link margin ensures that the communication link can still be established in case there are additional degradations during off-nominal or contingency situations. Missions must identify capability gained with less than 3 dB link margin and assess those benefits against the impact a smaller link margin may have on reliability.

Comm-231: All Lunar Exploration System uncoded communication links should have a frame error rate of less than or equal to 10^{-4} measured at the output of the received frame (post ASM frame sync).

Rationale: A frame error rate requirement is one factor in providing a robust communication channel.

Comm-232: All Lunar Exploration System coded communication links should have a frame error rate less than or equal to 10^{-7} at the output of the decoder.

Rationale: A bit error rate requirement is one factor in providing a robust communication channel. However, for links using block codes, frame

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error rate is a better performance measure. The value(s) of frame error rate specified for this application needs to be finalized.

3.4 VERIFICATION AND TESTING

It is the responsibility of the spacecraft developer to perform verification and validation. The majority of the standards will be verified using a combination of interface/compatibility testing, integrated end-to-end testing and analysis at the subsystem and system level.

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4.0 FUTURE TOPICS FOR POSSIBLE STANDARDIZATION

4.1 DETAILS TO PROVIDE "SUFFICIENCY FOR INTEROPERABILITY"

The protocols and standards currently defined in this standard are necessary to provide interoperability between systems and elements. The protocols and standards have different options and protocol stack dependent implementation details and these have been selected to a large extent to ensure that the interface is sufficiently defined to be interoperable. Future revisions of this standard may provide any additionalrequirements needed for interoperability.

4.2 POTENTIAL FUTURE EXTENSION OF STANDARDS AND PROTOCOLS

The ICSIS document addresses standards and protocols for Lunar Exploration Systems that will support Artemis and other Lunar Human Exploration efforts. Every effort is being made to ensure compatibility and extensibility of protocols and standards selected for cislunar missions to deep space human exploration missions. Future revisions of this document may include any modifications to the protocols and standards for deep space applicability. For example, the frequencies defined for the cislunar applications are per the near-Earth spectrum allocations. The frequencies for deep space excursions need to be added to be compliant with deep space spectrum allocations.

4.3 CONTINGENCY COMMUNICATIONS

The concept of operations to support spacecraft emergencies and contingencies is being worked at the Artemis level and the supporting interoperability standards for contingency/emergency communications are currently being discussed and worked at the IOAG LCAWG and ICSIS Working Group. Once the standards for contingency communications are agreed to by all the partners, it will be included in this Interoperability Standards document. Some guidance on the current thinking on the signaling and coding is currently provided under the Contingency Communications section of the document.

4.4 END-TO-END COMMUNICATIONS WITH MISSION CONTROL CENTERS

The current version of the document does not include any standards or protocols that specifies explicit requirements for the operation of space links, from the Mission Control Center, using Space Link Extension (SLE) services (such as Forward-Communication Link Transmission Units (F-CLTU), etc.) and Cross Support Transfer Services (CSTS) (e.g., Monitor Data-CSTS) protocols. Nor are there explicit requirements for space link layer capability to multiplex/de-multiplex multiple data streams to/from multiple destinations/sources in supporting DTN service. SLE and CSTS provide a consistent set of service interfaces for the variety of Earth Space Link Terminals that are likely to be used. Use of SLE and CSTS protocols is the surest way to get an interoperable architecture up to and including the network layer. CCSDS 901.1-M-1, Space Communications Cross Support – Architecture Requirements Document, provides a wealth of example deployments. Standards and protocols for these service interfaces may be addressed in a future release of this Standard.

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4.5 COMMERCIAL MISSIONS SPECTRUM MANAGEMENT

Commercial missions follow a slightly different spectrum management protocol and the ISS Program has developed a process to handle the different aspects of commercial spectrum management. Some Lunar Exploration Systems have plans to follow a process similar to ISS. Future version of this document may address commercial missions and payloads related spectrum management in further detail.

4.6 UNCREWED VEHICLES DOCKING WITH LUNAR EXPLORATION TARGET VEHICLE

There may be additional communication needs or capabilities unique to uncrewed vehicles (example: logistics vehicles) docking with the Orbiting Lunar Exploration System on the Rendezvous communication link. These capabilities and needs will be evaluated and section 3.2.2 will be updated as needed with standards and protocols to address these capabilities in a future version if needed.

4.7 NAVIGATION AND RADIOMETRIC TRACKING

This standard is set up to cover Position, Navigation, and Timing (PNT) functions. However, there is limited content on PNT services and interfaces in the current version due to a lack of PNT standards to reference. There is an effort within NASA's LunaNet framework to specify the standards to provide interoperable PNT services and navigation supporting capabilities. The PNT content will be updated as the PNT standard definitions mature.

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APPENDIX A - ACRONYMS AND ABBREVIATIONS

AES	Advanced Encryption Standard
AMS	Asynchronous Message Service
ANSI	American National Standards Institute
AOS	Advanced Orbiting Systems
ASM	Attached Sync Marker
BLE	Bluetooth Low Energy
BPSK	Binary Phase Shift Keying
BWG	Beam wave-guide
C&DH	Command and Data Handling
CADU	Channel Access Data Unit
CCSDS	Consultative Committee on Space Data Systems
CEPT	European Conference of Postal and Telecommunications Administrations
CFDP	CCSDS File Delivery Protocol
COTS	Commercial Off-the-Shelf
CSTS	Cross Support Transfer Services
dB	Decibel
DES	Digital Encryption Standard
DG	Data Group
DOR	Differential One-Way Ranging
DSN	Deep Space Network
DTE	Direct-to-Earth
DTN	Disruption Tolerant Networking
E_b/N_o	Energy per Bit-to-Noise Power Spectral Density Ratio
ECC	Electronics Communications Committee
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPC	Electronic Product Code
ERC	European Radiocommunications Committee
ESDMD	Exploration Systems Development Mission Directorate
ESTRACK	ESA Tracking Station Network
EVA	Extravehicular Activity
FCC	Federal Communications Commission
F-CLTU	Forward-Communication Link Transmission Units
FEC	Forward Error Correction
FIPS	Federal Information Processing Standards
FIPS PUB	Federal Information Processing Standards Publication
GCM	Galois/Counter Mode
GEO	Geosynchronous Equatorial Orbit

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GHz	gigaHertz
GMAC	Galois Message Authentication Code
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
HD	High Definition
HLS	Human Landing System
HPE	High-Photon Efficiency
I	Inphase
IASIS	International Avionics System Interoperability Standards
ICD	Interface Control Document
ICSIS	International Communication System Interoperability Standard
ITU	International Telecommunication Union
IEEE	Institute of Electrical and Electronics Engineers
IKE	Internet Key Exchange
IP	Internet Protocol
IPE	Internet Protocol Extension
IPSec	Internet Protocol Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IOAG	Interagency Operations Advisory Group
ISO	International Standards Organization
ISS	International Space Station
ITU	International Telecommunication Union
IV	Initialization Vector
IVA	Intra-Vehicular Activity
kbps	kilobits per second
km	kilometer
LANS	Lunar Augmented Navigation System
LCANWG	Lunar Communications Architecture and Navigation Working Group
LCAWG	Lunar Communications Architecture Working Group
LDPC	Low Density Parity Check
LDR	Low Data Rate
LLO	Low Lunar Orbit
LTE	Long Term Evolution
LTP	Licklider Transmission Protocol
LTV	Lunar Terrain Vehicle
MAC	Medium Access Control
MCB	Multilateral Coordination Board

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MCC	Mission Control Center
Mcps	megachips per second
MHz	megahertz
MOA	Memorandum of Agreement
MOC	Mission Operations Center
MOU	Memorandum of Understanding
MSB	Most Significant Bit
Mbps	Megabits per second
Msps	Mega symbols per second
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NRZ-L	Non-Return-to-Zero-Level
NRZ-M	Non-Return-to-Zero-Mark
NSN	Near Space Network
NTIA	National Telecommunications and Information Administration
OQPSK	Offset Quadrature Phase-Shift Keying
PCM	Pulse Code Modulation
PHY	Physical Layer
PM	Phase Modulation
PN	Pseudo Noise
PNT	Position, Navigation, and Timing
PSK	Phase Shift Keying
Q	Quadrature
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RF	Radio Frequency
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
RHCP	Right-Hand Circular Polarization
RPOD	Rendezvous, Proximity Operations, and Docking
SANA	Space Assigned Number Authority
SDLS	Space Data Link Security
SFCG	Space Frequency Coordination Group
SI	International System of Units
SLE	Space Link Extension
SN	Space Network
SNUG	Space Network Users' Guide
SQPN	Staggered Quadrature Phase Noise
SQPSK	Staggered Quadrature Phase Shift Keying

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SSCS	Space-to-Space Communication System
SS-UQPSK	Spread Spectrum Unbalanced Quadriphase Shift Keying
TBD	To Be Determined
TBR	To Be Resolved
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TM	Telemetry
TTC	Telemetry, Tracking, and Command
UDP	User Datagram Protocol
UE	User Equipment
UHF	Ultra-High Frequency
USLP	Unified Space Link Protocol
VCP	Virtual Channel Packet
VV	Visiting Vehicle
XML	Extensible Markup Language

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APPENDIX B - GLOSSARY OF TERMS

BENT PIPE

Header of data is read and processed or modified, as needed, and (header + data) sent on to the correct user. Actual user or payload data is not processed or modified.

RELAY

Forward data from Lunar Exploration System elements/payloads on to its destination, store data if link is not available

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APPENDIX C - OPEN WORK

Table C-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBD item is numbered based on the section where the first occurrence of the item is located as the first digit and a consecutive number as the second digit (i.e., <TBD 4-1> is the first undetermined item assigned in Section 4 of the document). As each TBD is solved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

TABLE C-1 TO BE DETERMINED

TBD	Section	Description
3-1	3.2.2.2.1.7, 3.2.2.2.2.1.6, 3.2.2.6.7	Standard for key management – CCSDS is working on a standard for this. Replace **<TBD 3-1>** when this standard gets baselined and all International Partners agree to implement it.
3-3	3.2.2.4.4	Need to determine security needs and requirements/standards for EVA communications
3-5	3.2.2.2.2.2	Optical Standards are still being worked by CCSDS. Once they have been finalized and agreed to by the International Partners, they will be added to the document
3-6	3.2.2.5	RFID tag encoding standard needs to be added
3-7	3.2.2.1.3	Providing metadata with imagery is open since there is not an international standard for it. There is a NASA STD 2822 for it and CCSDS is working on CCSDS 876.0-R-3, Spacecraft Onboard Interface Services – XML Specification For Electronic Data Sheets (baselined in Dec. 2019 – need to review and agree to)
3-8	3.2.2.2.3	Need to develop contingency communications standards

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Table C-2 lists the specific To Be Resolved (TBR) issues in the document that are not yet agreed to. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBR issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBR 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

TABLE C-2 TO BE RESOLVED

TBR	Section	Description
3-7	3.2.2.2.1.6.2, 3.2.2.2.2.1.5.2, 3.2.2.6.6.2	Need to resolve whether LTP is a requirement (“shall”) for cislunar operational links or it is something to “test” at cislunar and require for deep space exploration missions when the time delays are greater.
3-14	3.2.2.2.1.6.4, 3.2.2.2.2.1.5.4, 3.2.2.6.6.4	Need to resolve if AMS is a requirement - AMS is not needed to use CFDP, and in fact, CFDP is most often without AMS.
3-17	3.2.2.2.1.6.3, 3.2.2.2.2.1.5.3, 3.2.2.3.6, 3.2.2.6.6.3	Resolve need for TCP Convergence layer adapter
3-31	3.2.2.8	Need to finalize the need for data link security on LunaSAR links
3-32	3.2.2.8	Need to resolve the number of users simultaneously supported by LunaSAR
3-33	3.2.2.8	Need to resolve the maximum range supported by LunaSAR
3-34	3.2.2.8	Need to resolve the LunaSAR transmission schedule definition
3-35	3.2.2.8	Need to resolve presence of UHF Lunar Orbiter capability and applicability to Artemis
3-36	3.2.2.8	Need to resolve whether LunaSAR will use the spreading codes in CCSDS 415.1-B-1
3-37	3.2.2.8	Need to resolve the Distress Message Content location

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APPENDIX D – DATA TRANSFER DETAILS

CSP – Earth (Downlink) ---- Uncrewed (periodic coverage)
1. Health and Status data
2. Engineering and Science Data
3. Caution and Warning (low latency)
4. File downloads
5. Camera images/Video (near real-time and stored)
6. Relayed health and status, etc. from other modules
7. Support Radio Frequency ranging (Radiometric tracking)

CSP to Earth (Downlink) ---- Crewed (near 24/7 towards less frequent coverage)
1. Health and Status data
2. Engineering and Science Data
3. Caution and Warning (low latency)
4. File downloads
5. Camera images/Video (near real-time and stored)
6. Relayed health and status, etc. from other modules
7. Relayed EVA data
8. Support Radiometric tracking
9. Audio (near real-time and stored)
10. Video Conferencing
11. Email, family communications, texts, etc.
12. Internet apps use

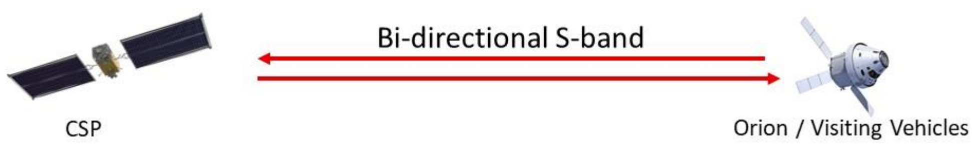
24/7 availability, low rate spacecraft TT&C links to support unplanned contingencies and spacecraft emergency (low latency)

Earth to CSP (Uplink) ---- Uncrewed (periodic coverage)
1. Commands
2. Configuration initialization and updates
3. GNC State information
4. Software updates
5. Data uploads (procedures, files, images, etc.)
6. Relayed Commands, etc. to other modules
7. Support Radio Frequency ranging (Radiometric tracking)

Earth to CSP (Uplink) ---- Crewed (near 24/7 towards less frequent coverage)
1. Commands
2. Configuration initialization and updates
3. GNC State Information
4. Software updates
5. Data uploads (procedures, files, images, etc.)
6. Relayed Commands, etc. to other modules
7. Relayed commands/information for EVAs
8. Support Radiometric tracking
9. Audio (near real-time)
10. Video Conferencing
11. Email, family communications, texts, etc.
12. Internet apps use

24/7 availability, low rate spacecraft TT&C links to support unplanned contingencies and spacecraft emergency (low latency)

FIGURE D-1 DATA TRANSFER BETWEEN GATEWAY AND EARTH



CSP to Orion/VV ---- during Rendezvous and Docking/berthing
1. Health and Status data
2. Caution and Warning
3. Relayed health and status, etc. from other modules
4. Support Radiometric tracking
5. Audio (real-time)
6. Images

During rendezvous and docking, Orion/VV data can be relayed to ground via the Gateway-Ground link as a backup to the Orion/VV-ground link

Orion/VV to CSP ---- during Rendezvous and Docking/berthing
1. Commands
2. Configuration updates
3. Data uploads (procedures, files, images, etc.)
4. Radiometric tracking
5. Audio (real-time)

During rendezvous and docking, Gateway data can be relayed to ground via the Orion/VV-Ground link as a backup to the Gateway-ground link

FIGURE D-2 NOTIONAL DATA TRANSFER BETWEEN LUNAR EXPLORATION TARGET VEHICLE AND VISITING VEHICLE (EXAMPLE: ORION)

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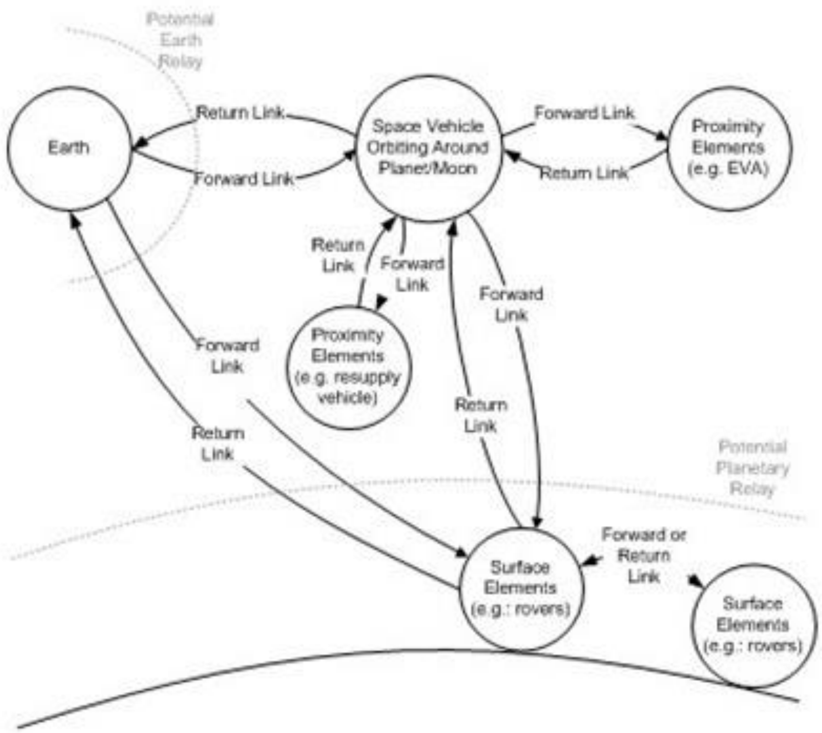
APPENDIX E – FUNCTIONAL DATA FLOW GENERIC LUNAR/PLANETARY MISSION



NOTE: Communication links are shown between surface elements as well as between surface elements and Earth for completeness.

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APPENDIX F – DATA RATE BASIS OF ESTIMATES

Communication Link	**Forward Link**	**Return Link**	**Data Rate Justification**
Earth to Space Vehicle in Cislunar Orbit & Earth to Space Vehicle while on excursion to Mars (and other Deep Space Destinations)	2 - 15+ Mbps (Target 25+ Mbps)	10 - 100+ Mbps	Forward Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~100 kbps for commands: (ISS has ~40 kbps for commands, double to account for attached elements & surface vehicles + add 20kbps for margin) • ~100 kbps for Software uploads: Full On-Board SW Upload ~100 Mbps; Assuming 1 hour contact time with Earth and full SW upload in that 1 hour and using a factor of 4 margin gives ~100 kbps • ~1-2 Mbps for mission planning: (procedures, file transfers, etc.) • ~2+ Mbps Video/imagery: minimum 1 channel 1080p HD @ 2 Mbps, more likely 5 Mbps (if 4K, then 8 Mbps best case or 16 Mbps conservative case) • ~2+ Mbps crew communications (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps)) • Support Crew psychological health - ~5 Mbps Return Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~450 kbps for telemetry (operational, crew health and status, situation awareness). Includes telemetry from attached elements • 80+ Mbps Engineering/Science/Video: assume 2 channels 4K video is 32 Mbps, double for margin and add another 16 Mbps to account for relay of video for surface assets, etc. • ~1-2 Mbps file transfers, etc. • ~2+ Mbps crew communications (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps))

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<table>
<tr><th>Communication Link</th><th>Forward Link</th><th>Return Link</th><th>Data Rate Justification</th></tr>
<tr><td>Space Vehicle to Moon & Mars Surface Elements (and other Deep Space Destinations)</td><td>1-10+ Mbps</td><td>5- 25+ Mbps</td><td>Forward Link: Allows:
• ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used)
• ~50 kbps for commands
• ~25 kbps for Software uploads: Full On-Board SW Upload ~100 Mbps; Assuming 1 hour contact time with and full SW upload in that 1 hour gives ~25 kbps
• ~1-2 Mbps for mission planning: (procedures, file transfers, etc.)
• ~2+ Mbps Video/imagery: minimum 1 channel 1080p HD @ 2 Mbps, more likely 5 Mbps (if 4K, then 8Mbps best case or 16 Mbps conservative case)
• ~2+ Mbps crew communications (relayed) (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps))

Return Link: Allows:
• ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used)
• ~450 kbps for telemetry (operational, crew health and status, situation awareness). Includes telemetry from attached elements
• 16+ Mbps Engineering/Science/Video: assume 1 channels 4K video is 8 Mbps, double for margin.
• ~1-2 Mbps file transfers, etc.
• ~2+ Mbps crew communications (relayed) (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps))</td></tr>
<tr><td>Element to Element on Surface of Destination</td><td colspan="2">1- 20+ Mbps
(two-way comm)</td><td>Exchange:
• ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used)
• ~100 kbps for command and telemetry
• ~1-2 Mbps for mission planning: (procedures, file transfers, etc.)
• ~2+ Mbps Video/imagery: minimum 1 channel 1080p HD @ 2 Mbps, more likely 5 Mbps (if 4K, then 8Mbps best case or 16 Mbps conservative case)</td></tr>
</table>

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Communication Link	Forward Link	Return Link	Data Rate Justification
Space Vehicle and Element in proximity of Space Vehicle such as a resupply vehicle or EVA crewmember	up to 1 Mbps	up to 10 Mbps	Forward Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~100 kbps for range, Doppler measurements, command, telemetry (in case it needs to be relayed to Earth), etc.; • ~500 kbps for video/images (not necessarily HD or 4K – support GN&C during rendezvous and docking) Return Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~450 kbps for telemetry (operational, crew health and status, situation awareness). Includes telemetry from attached elements • 8 Mbps Video: assume 2 channels HD @4Mbps/channel.
Earth and Element on Surface of Moon & Mars (and other Deep Space Destinations)	at least 16 kbps	at least 256 kbps	Forward Link: Allows: • ~10 kbps for audio: 1 channels (assuming ~ 10 kbps per channel depending on compression used) • ~2-6 kbps for commanding Return Link: Allows: • ~10 kbps for audio: 1 channels (assuming ~ 10 kbps per channel depending on compression used) • ~240 kbps for telemetry (operational, crew health and status, situation awareness, science etc.).

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APPENDIX G – CCSDS STANDARDS DEVELOPMENT SCHEDULE

RESERVED

DRAFT

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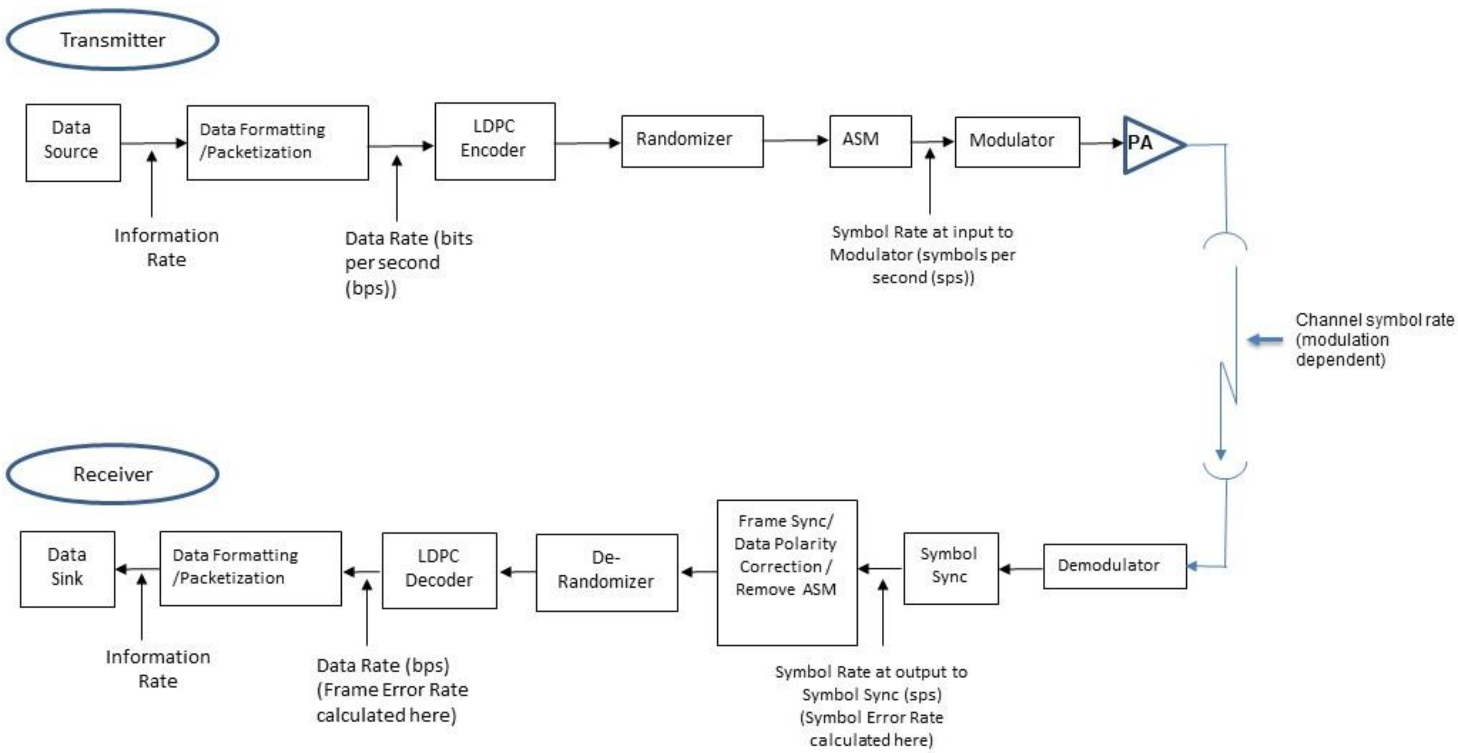
APPENDIX H – REFERENCE LINK MARGINS

The margins provided in this Appendix is **for reference purposes only**. It provides a methodology for calculating link margins. It does not imply preference towards a particular architecture, hardware or implementation solution.

Figure H-1 shows the nomenclature and reference points for measuring the link performance.

FIGURE H-1 LINK PERFORMANCE NOMENCLATURE



Bit/Symbol Rate Nomenclature

- Bit - basic unit of information that is being transferred between the data input and data output
  - For coded links, it is the data unit input to the Forward Error Correction (FEC) encoder or output of the FEC decoder
  - For uncoded links:
    - With an Asynchronous Sync Marker (ASM), it is the data unit before the ASM is added or after the ASM is removed
    - Without an ASM, it is the data unit input to the modulator or the output of the demodulator and is equivalent to a symbol
- Data Rate (Rb) → The number of bits per second transferred between data source and data sink
- Symbol is the data unit at the input of the modulator and output of the demodulator.

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Gateway to Earth Link (Gateway Ka-band to DSN, 100 Mbps)

	Node	Parameter	Value	Unit	Inputs and Comments	Source
1	Gateway	Transmit Power	**23.0**	dBW	200W TWTA	Calculated assuming 200W TWTA
2	Gateway	Circuit Loss	**-3.0**	dB		
3	Gateway	Antenna Gain	**45.8**	dB	HGA002, 1m Ka Reflector, 50% Efficiency	Calculated assuming 1m reflector, 50% efficiency
4	Gateway	Antenna Pointing Loss	**0.0**	dB	TBD	TBD
5	Gateway	EIRP	**65.8**	dBW	(1)+(2)+(3)+(4)	Comparable to: LRO Ka-band HGA (58.9 dBW)
6	Channel	Distance	**450,000**	km	Distance in km	
7	Channel	Center Frequency	**26250**	MHz	Center of downlink band (25.5 - 27.0 GHz)	
8	Channel	Free Space Loss	**-233.9**	dB	20 log10 (6) + 20 log10 (7) + 32.45	ITU Rec P525-3 , Calculation of Free-Space Attenuation, Eq. 4
9	Channel	Polarization Loss	**0.0**	dB	Gateway Axial Ratio: TBD DSN Axial Ratio: TBD	TBD TBD
10	Channel	Total Atmospheric Loss	**0.0**	dB	Incorporated in G/T	
11	Channel	RFI Losses	**0.0**	dB	TBD	TBD
12	DSN	Total Received Power at Antenna	**-168.1**	dBW	(5)+(8)+(9)+(10)+(11)	
13	DSN	Antenna Pointing Loss		dB		
14	DSN	Antenna Gain		dB	Calculation of G/T not required, G/T spec'd by DSN	
15	DSN	Circuit Loss		dB		
16	DSN	System Noise Temperature (T)		dBK		
17	DSN	Receive G/T	**58.2**	dB/K	(13)+(14)+(15)-(16), or reference document	DSN Services Catalog Rev F, Table 3.5. G/T is referenced to 45-deg elevation, 90% weather condition, and diplexed configuration.
18	DSN	Total Received Power at Input (Prec)		dBW		
19	DSN	Noise Spectral Density (No)		dBW/Hz	G/T provided, explicit calculation of No not required	
20	DSN	Received Prec/No	**118.7**	dBHz	(12)+(17)-10 log10 (K)	K (Boltzmann's Constant) = 1.38e-23 W/K/Hz
21	DSN	Modulation Loss	**0.0**	dB	Does not apply to this link.	
22	DSN	Receive Symbol Rate	**200.0**	Msps	Symbol rate at output of the demodulator	
23	DSN	Receive Symbol Rate	**83.0**	dBHz	10*log10(22)	
24	DSN	Received Es/N0	**35.7**	dB	(20)+(21)-(23)	
25	DSN	Implementation Loss	**-3.0**	dB	Assumption	
26	DSN	Available Es/N0 at symbol synchr	**32.7**	dB	(24)+(25)	
27	DSN	Effective Code Rate (including ASI	**-3.02**	dB	LDPC frame: 16384 data bits per 32832 symbol CADU (32768 coded symbols and 64 bit ASM)	
28	DSN	Available Eb/N0 (at decoder)	**35.7**	dB	(26)-(27). Calculated for reference only.	
29	DSN	Required Eb/N0	**1.0**	dB	LDCP 1/2, FER 1e-7, block size = 16384	"TM Synchronization and Channel Coding", CCSDS 130.1-G-2, Fig. 8-8
30	DSN	Required Es/No	**-2.0**	dB	(27+(29). For reference only.	
		Margin	**34.7**	dB	(26)-(30)	

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Earth to Gateway Link (NSN X-band to Gateway, 5 Mbps)

	Node	Parameter	Value	Unit	Inputs and Comments	Source
1	NEN	Transmit Power		dBW		
2	NEN	Circuit Loss		dB		
3	NEN	Antenna Gain		dB		
4	NEN	Antenna Pointing Loss		dB		
5	NEN	EIRP	**86.0**	dBW	(1)+(2)+(3)+(4), or reference	USHI02 13m EIRP = 86 dBW. Near Earth Network User's Guide
6	Channel	Distance	**450,000**	km	Distance in km	
7	Channel	Center Frequency	**7213**	MHz	Center of uplink band (7.190 - 7.235 GHz)	
8	Channel	Free Space Loss	**-222.7**	dB	20 log10 (6) + 20 log10 (7) + 32.45	ITU Rec P525-3 , Calculation of Free-Space Attenuation, Eq. 4
9	Channel	Polarization Loss	**0.0**	dB	Gateway Axial Ratio: TBD	TBD
					NEN Axial Ratio: TBD	TBD
10	Channel	Total Atmospheric Loss	**-1.5**	dB	From NENUG for USHI Elevation: 10 deg, Exceedence Probability: 1%	
11	Channel	RFI Losses	**0.0**	dB	TBD	TBD
12	Gateway	Total Received Power at Antenna	**-138.1**	dBW	(5)+(8)+(9)+(10)+(11)	
13	Gateway	Antenna Pointing Loss	**0.0**	dB	TBD	TBD
14	Gateway	Antenna Gain	**34.6**	dB	HGA001, 1m X Reflector, 50% Efficiency	
15	Gateway	Circuit Loss	**-3.0**	dB	Estimate from similar mission	
16	Gateway	System Noise Temperature (T)	**25.0**	dBK	Estimate from similar mission	
17	Gateway	Receive G/T	**6.6**	dB/K	(13)+(14)+(15)-(16)	
18	Gateway	Total Received Power at Input (Prec)		dBW		
19	Gateway	Noise Spectral Density (No)		dBW/H	G/T provided, explicit calculation of No not required	
20	Gateway	Received Prec/No	**97.1**	dBHz	(12)+(17)-10 log10 (K)	K (Boltzmann's Constant) = 1.38e-23 W/K/Hz
21	Gateway	Modulation Loss	**0.0**	dB	Does not apply to this link.	
22	Gateway	Receive Symbol Rate	**10.0**	Msps	Symbol rate at output of the demodulator	
23	Gateway	Receive Symbol Rate	**70.0**	dBHz	10*log10(22)	
24	Gateway	Received Es/N0	**27.1**	dB	(20)+(21)-(23)	
25	Gateway	Implementation Loss	**-3.0**	dB	Assumption	
26	Gateway	Available Es/N0 at symbol synchronizer	**24.1**	dB	(24)+(25)	
27	Gateway	Effective Code Rate (including ASM overhead)	**-3.02**	dB	LDPC frame: 16384 data bits per 32832 symbol CADU (32768 coded symbols and 64 bit ASM)	
28	Gateway	Available Eb/N0 (at decoder)	**27.1**	dB	(26)-(27). Calculated for reference only.	
29	Gateway	Required Eb/N0	**1.0**	dB	LDCP 1/2, FER 1e-7, block size = 16384	"TM Synchronization and Channel Coding", CCSDS 130.1-G-2, Fig. 8-8
30	Gateway	Required Es/No	**-2.0**	dB	(27+(29). For reference only.	
		Margin	**26.1**	dB	(26)-(30)	

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Gateway to Visiting Vehicle Link – Reference Margin (3 Mbps)

	Node	Parameter	Value	Unit	Inputs and Comments	Source
1	Gateway	Transmit Power	**13.0**	dBW	20W Transmitter	Calculated assuming 20W Transmitter
2	Gateway	Circuit Loss	**-3.0**	dB		Assumption
3	Gateway	Antenna Gain	**0.0**	dB	Assumption	Assumption based off hemispherical antenna with ±60deg FOV
4	Gateway	Antenna Pointing Loss	**0.0**	dB	TBD	TBD
5	Gateway	EIRP	**10.0**	dBW	(1)+(2)+(3)+(4)	
6	Channel	Space Loss	**-139.3**	dB	Distance: 100 km Center Freq: 2203.2 MHz	
7	Channel	Polarization Loss	**-0.8**	dB	Gateway Axial Ratio:2.0 VV Axial Ratio: 6.0	Assumption for circularly polarized antenna Sample VV axial ratio with phased antenna array (PAA)
8	Channel	Total Atmospheric Loss	**0.0**	dB	N/A	
9	Channel	RFI Losses	**0.0**	dB	TBD	TBD
10	VV	Total Received Power at Ant	**-130.1**	dBW	(5)+(6)+(7)+(8)+(9)	
11	VV	Antenna Pointing Loss	**-0.2**	dB		Sample pointing loss
12	VV	Antenna Gain		dB	Calculation of G/T not required, G/T spec'd bysample VV flight unit test	
13	VV	Circuit Loss		dB		
14	VV	System Noise Temperature (T)		dBK		
15	VV	Receive G/T	**-24.4**	dB/K	(11)+(12)+(13)-(14), or Reference case	Sample VV flight unit measured data with worst-case temperature, metallic tape, etc. ±60deg FOV from each PAA yielding ~97.6% spherical coverage and 100% coverage in forward hemisphere
16	VV	Total Received Power at Input (Prec)		dBW		
17	VV	Noise Spectral Density (No)		dBW/Hz	G/T provided, explicit calculation of No not required	
18	VV	Received Prec/No	**73.9**	dBHz	(10)+(15)-10*log10(K)	K (Boltzmann's Constant) = 1.38e-23 W/K/Hz
19	VV	Received Symbol Rate	**67.8**	dBHz	10*log10(6 Msps)	
20	VV	Received Es/No	**6.1**	dB	(18)-(19)	after demodulator
21	VV	Effective Coding Rate	**-3.1**	dB	10*LOG10(1024/(2048+64))	LDPC frame: 1024 data bits per 2112 symbol CADU (2048 coded symbols and 64bit ASM)
22	VV	Required Es/No	**2.3**	dB	OQPSK, LDPC=1/2,SER 10e-7 after demodulator, block size = 1024	"TM Synchronization and Channel Coding", CCSDS 130.1-G-2, Figure 8-8
23	VV	Implementation Loss	**-3.0**	dB	Nominal loss (-2 dB) with 1 dB additional loss	MMS RF Interface Control Documents (RFICD) #450-RFICD-MMS/DSN/NEN/SN
		Margin	**3.9**	dB	(20)-(21)-(22)+(23)	

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Visiting Vehicle Link to Gateway – Reference Margin (36 kbps)

	Parameter	Units	Value	Notes
	Symbol rate		**72 ksps**	
1	VV EIRP	dBW	11.5	Generic VV EIRP
2	VV transmit pointing loss	dB	-0.2	VV link budget parameter
3	Effective EIRP	dBW	11.3	(1)+(2)
	Range	km	100.0	
	Frequency	MHz	2028.78	ProxB forward frequency
4	Space Loss	dB	-138.6	
5	Other Losses	dB	0.0	TBD
6	Power received by isotropic antenna	dBWi	-127.3	(3)+(4)+(5)
	VV Axial Ratio	dB	7.0	Generic VV Axial Ratio
	Gateway Axial Ratio	dB	2.0	Assumption
7	Polarization Loss	dB	-1.0	
8	Gateway antenna pointing loss	dB	0.0	N/A for fixed antenna
9	Gateway receive antenna gain	dB	0.0	Assumption
10	Gateway receive circuit loss	dB	-3.0	Assumption
11	Total receive power at receiver input (P_{rec})	dBW	-131.3	(6)+(7)+(8)+(9)+(10)
	Gateway noise figure at receiver input	dB	2.0	Assumption
	Gateway cable thermal noise temperature	K	290.0	Assumption
	Gateway antenna noise temperature	K	220.0	Assumption based on prior analysis for spacecraft in LLO
12	System noise temperature referenced to receiver input	dBK	26.3	
13	Receive G/T	dB/K	-29.3	(8)+(9)+(10)-(12). Calculated for reference only.
14	Noise Spectral Density (N_0)	dBW/Hz	-202.3	Boltzmann's Constant plus system noise temp at receiver input
15	Receive Prec/No	dBHz	71.0	(11)-(14)
16	Modulation Loss	dB	-0.4	10*log10(10/11) for SS-UQPSK forward link with 10:1 I:Q (command:ranging) quadrature channel power ratio
17	Receive symbol rate	dBHz	48.6	
18	Received Es/No (command channel)	dB	22.0	(15)+(16)-(17)
19	Implementation Loss	dB	-3.0	Assumption
20	Available Es/No at symbol synchronizer	dB	19.0	(18)+(19)
21	Effective Code Rate (including ASM overhead)	dB	-3.1	MPCV LDPC frame: 1024 data bits per 2112 symbol CADU (2048 coded symbols and 64bit ASM)
22	Available Eb/No (at decoder)	dB	22.1	(20)-(21). Calculated for reference only.
23	Required Es/No	dB	-0.8	Threshold for CWER = 1e-7
24	Required Eb/No	dB	2.3	(23)-(21). For reference only.
25	Link Margin	dB	**19.8**	(20)-(23)

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