International Communication System Interoperability Standards (ICSIS)

Revision A – September 2020

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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

PREFACE

INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS (ICSIS)

This International Communication System Interoperability Standards (ICSIS) is to ensure end-to-end compatibility and interoperability between a Cislunar Space Platform, visiting spacecraft, as well as Lunar Systems and Earth, enabling collaborative endeavors.

Configuration control of this document is the responsibility of the Multilateral Coordination Board (MCB). The National Aeronautics and Space Administration (NASA) will maintain the International Communication System Interoperability Standard (ICSIS) under Human Exploration and Operations Mission Directorate (HEOMD) Configuration Management. Any revisions to this document will be approved by the MCB.

INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS

CONCURRENCE

MARCH 2019

Associate Administrator for Human Exploration and Operations National Aeronautics and Space Administration	Date
Executive Director of Human Space Programs State Space Corporation Roscosmos	Date
Director of Human and Robotic Exploration European Space Agency	Date
Director General, Space Exploration Canadian Space Agency	Date
Deputy Director General Research and Development Bureau Ministry of Education, Culture, Sports, Science, and Technology	Date

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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) membership to establish interoperable and compatible communications 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 functional, interface and performance standards necessary to support interoperable and compatible communications between human exploration spacecrafts, ground infrastructure, and other space and surface vehicles that interface with human exploration spacecrafts. The scope of the standard is for deep space human spaceflight missions and spacecraft that interface with human missions (i.e. visiting vehicles, landers, etc.). The focus of this version of the document is on a space vehicle/platform used for human exploration in cislunar space, a Cislunar Space Platform (CSP), and its interfaces. This CSP could be transiting in space, on the lunar surface, or orbiting the moon. Extensibility to other deep space human missions has also been considered and where practicable the document includes content that is also relevant to future deep space human exploration missions. Future revisions of the document will incorporate any additional information or modifications needed for deep space human exploration missions. Further definition of what is covered in the current version and what will be addressed in future revisions is given in Table 3.2-1, Current Standards Content.

Interoperable, cross supportable, and compatible communications 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 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;
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 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 will 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 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 working group for review.

Configuration control of this document is the responsibility of the Multilateral Coordination Board (MCB). NASA will maintain the ICSIS document under Human Exploration and Operations Mission Directorate (HEOMD) Configuration Management. Any revisions to this document will be approved by the MCB.

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-R-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 503.0-B-1	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)
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 802.11n, 5.0 GHZ IEEE 802.11ac, 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 32-2R1	Communication Frequency Allocations and Sharing in the Lunar Region
RFC 768	User Datagram Protocol (August, 1980)
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
450-SNUG	Space Network Users' Guide (SNUG)
453-NENUG	Near Earth 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 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
DSN 820-100	Deep Space Network Services Catalog
NASA STD-2822	Still and Motion Imagery Metadata Standard
CCSDS 883.0	CCSDS Wireless Proximity Network Standard, Draft

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 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 and compatibility with partner assets (ground stations, relay satellites, etc.). The communication 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).

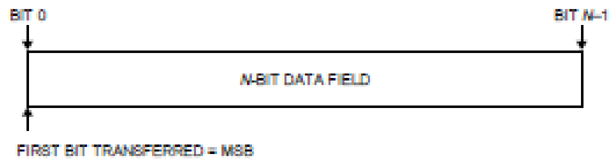


FIGURE 3.1.1-1 BIT NUMBERING CONVENTION

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 INTERFACES

The CSP communication system includes the necessary equipment to handle all data, audio and video communications within the spacecraft and interfaces with the Command and Data Handling (C&DH) system as well as all other in-space vehicles, lunar surface vehicles, and ground communication sites.

The term CSP-Ground is used in the interface definitions and standards. “CSP-Ground” is 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-Earth Network (NEN), 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. A “Lunar System” is an asset or CSP 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, rovers, habitats, other payloads, CubeSats, science instruments, etc.

The following sections describe the communication interfaces and provides the standards to be used to provide interoperability and compatibility.

The standards defined in the following sections are for a CSP used for human exploration missions and its 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. Future revisions of the document will incorporate additional information or modifications needed for deep space human exploration missions. Interfaces included in the current version and what will be addressed in future revisions is given in Table 3.2-1, Current Standards Content.

TABLE 3.2-1 CURRENT STANDARDS CONTENT

Interface	Addressed in Current Standard
Crewed and Uncrewed Visiting Vehicles which Dock/Berth with Cislunar Space Platform	Covered in current version. Any unique requirements for uncrewed vehicles (e.g., Logistics) is being addressed as part of future work
Free Flyers (e.g., Small Satellites) which interface with Cislunar Space Platform	Covered in current version.
Crewed Vehicles in Low Lunar Orbit (LLO)	Comm with CSP is covered in current version. Comm with Earth, can use standards in current version; additional standards will be addressed as future work.
Crewed & Uncrewed Lunar Landers which transit between Lunar Surface and Cislunar Space Platform	Covered in current version.
Crewed Mars Transporters	Modification Required, addressed as part of future work
Crewed Lunar Bases	Comm with CSP is covered in current version. Comm with Earth can use standards in current version; additional standards lunar surface communications will be addressed as future work.
External-vehicle activity	Comm between CSP and external-vehicle activity covered in current version.
Internal and external payloads	Covered in current version (Wireless communications).

With the diverse missions being planned, we can have a CSP that is in orbit providing a platform for conducting research and experiments, crew habitation, staging other missions, etc. and remains an orbiting CSP for years. We can have another CSP come as a visiting vehicle and perform rendezvous, proximity operations and docking (RPOD) with the orbiting CSP. The two CSPS would communicate over the CSP to Visiting Vehicle link. The visiting CSP can undock from the orbiting CSP and transit to the Lunar Surface; during this transit to/from as well as surface operations phase, this CSP is a Lunar system and the two CSPs would communication over the CSP – Lunar Systems link. Therefore, based on the mission phase, a CSP can play different roles, it could be an orbiting CSP, a visiting vehicle, or a lunar system (transiting CSP, landed CSP or a deployed CSP) and would communicate using the appropriate interfaces.

The standards and protocols provide for the minimum capability required to support interoperable communications across that interface at the physical, space data link, and network layers plus at some select application layers. This allows for a ground station (or relay) to be able to communicate with the CSP during nominal or contingency operations. It is also expected that the CSP would be able to forward data between interfaces using either network layer routing or link layer switching. Therefore, if a CSP element implements an interface, then for the functions implemented on that interface, that element needs to, as a minimum, follow the respective standards defined in this document. For example, if an element has a high rate Radio Frequency (RF) link with Earth, then it will need to follow the standards given in Section 3.2.2.2.2.1. The element can implement additional capabilities for its unique needs as long as it includes the standards and protocols for that interface provided in the following sections. The document is organized to facilitate this by defining all the requirements by function for each interface, thus making it "stand alone".

3.2.1 DESCRIPTION OF INTERFACES

The CSP communication system includes the following RF interfaces:

- A long-range, low data rate interface with Earth Systems (direct-to-Earth or via relay) that enables a standard, reliable path for basic command and telemetry operations. Standards are also provided for contingency communication operations which will be performed over this interface to recover from spacecraft emergencies and contingencies;
- 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;
- 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 CSP and a VV;
- An short range interface that enables core communications between Extravehicular activity (EVA) systems: EVA to EVA as well as EVA to CSP;
- Internal and external wireless local area networked communications enabling high rate communications between the Intra-vehicular activity (IVA), EVA, cameras, crew laptops and devices, sensors, free flying robotic cameras, payloads, etc.;
- A mid-range interface with Lunar Systems (direct link or via a relay) that enables data exchange between the CSP and assets on the lunar surface, orbiting the moon or in the vicinity of the moon.

The standards for audio and video communications between CSP and endpoints as well as within CSP elements are defined in this document. The data bandwidth 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 performed by the VSM 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 situation and must not be interrupted by something like video or lower priority data transmission. There are hardline interfaces between the attached elements to allow data transfer (including audio and video) between the elements and this hardline interface is further defined in the International Avionics System Interoperability Standards (IASIS), and not covered in this document.

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

The detailed breakdown of data transferred between CSP and Earth and between CSP and a VV is given in Appendix D. Similar data would be transferred between the CSP and Lunar systems, EVAs, payloads, etc. Functional data flow between the elements for a generic cislunar/planetary mission is given in Appendix E.

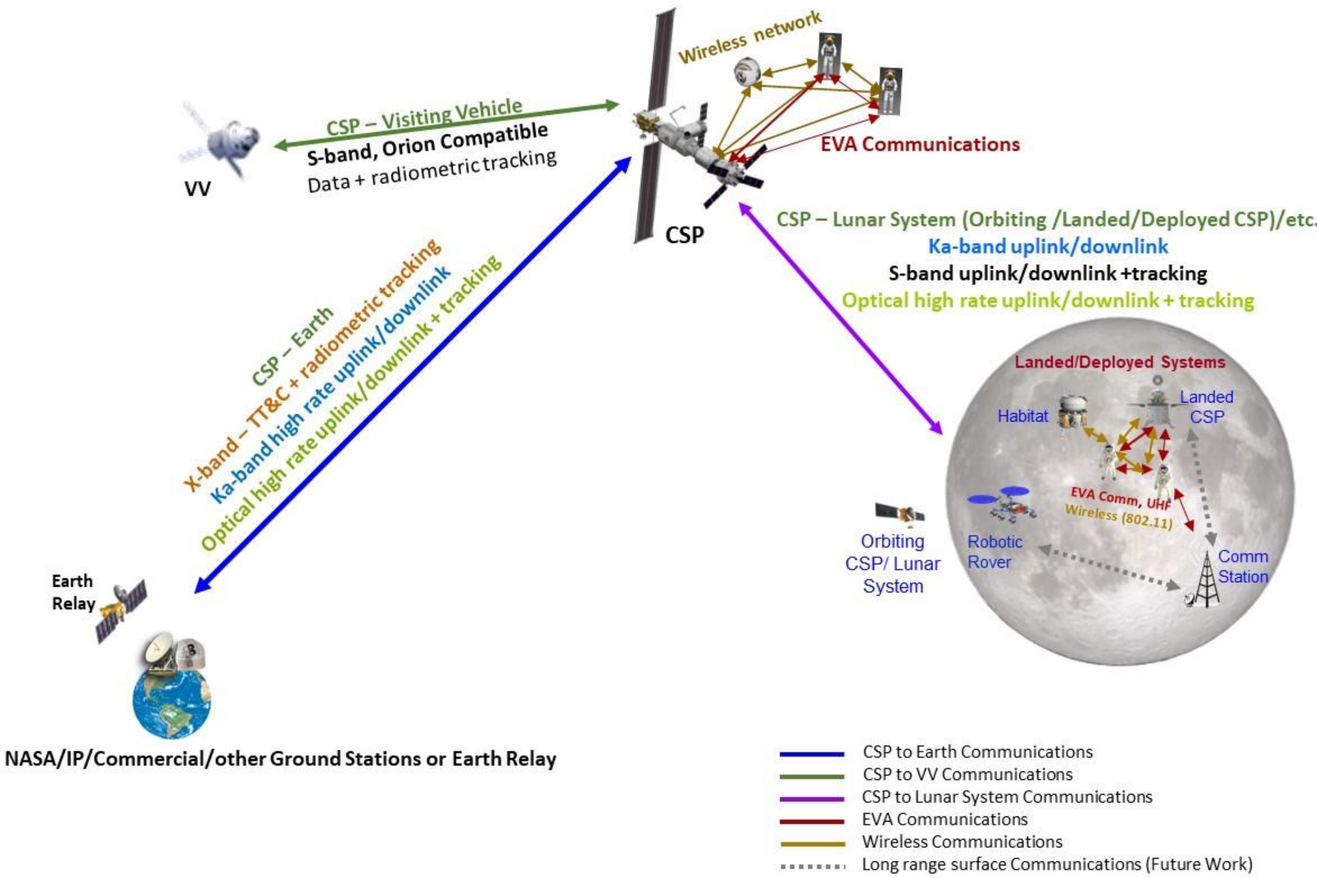


FIGURE 3.2.1-1 CSP COMMUNICATION INTERFACES

3.2.2 INTERFACE STANDARDS

3.2.2.1 GENERAL

This section has communication interoperability requirements common to all CSP links.

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: CSP shall comply with radio frequency selection as defined in REC SFCG 32-2R1, 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: CSP 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: CSP elements' RF systems shall be compatible with other CSP 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 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 CSP, will use the CSP audio communications to communicate with each other and VV crew, communicate with EVA crew, for discussions with CSP-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: CSP shall comply with CCSDS 766.2-B-1, Voice and Audio Communications, for all voice and audio exchanges.

Rationale: Crew on a CSP will need voice and audio communications with CSP-Ground, VVs, Lunar assets, EVAs, etc. and having interoperable communications between them is essential to save cost, complexity and size weight and power.

Comm-4: CSP 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: CSP audio system needs to meet the intelligibility requirements to ensure that the audio and voice of different speakers over the system is comprehensible under different conditions.

Comm-5: DELETED

3.2.2.1.3 VIDEO

A CSP'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, CSP's video formats, interfaces, encapsulation, and transmission protocols need to be consistent with CCSDS 766.1-B-2, Digital Motion Imagery, where practical depending on interoperability with avionics, human system interfaces, and other areas where video interoperates with other systems.

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

Rationale: CSP elements 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: CSP shall acquire and distribute multiple resolutions and frame rates consistent with CCSDS 766.1-B-2, Digital Motion Imagery.

Rationale: CSP elements 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: CSP 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).*

Comm-9: CSP 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 CSP TO EARTH COMMUNICATION LINKS

The subsections below contain the communication standards specific to the CSP to Earth Links. The CSP to Earth links are broken into the Command and Telemetry 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.). 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 CSP 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 CSP; and
2. Health and status data, engineering/science/payload data, file downloads, audio, video, etc. from CSP to Earth.

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

3.2.2.2.1 COMMAND AND TELEMETRY COMMUNICATION LINKS

The Command and Telemetry link provides for the core communications to command and monitor CSP. It is also used to track the CSP 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 support by NASA or partners);

G. Availability of space heritage, mature technology.

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

TABLE 3.2.2.2-1 REQUIRED STANDARDS FOR CSP COMMAND AND TELEMETRY LINK

X-band Forward Link (7190-7235 MHz)[6] (Earth to CSP)					
Symbol Rates[1, 10]	**Modulation and Encoding[1, 10]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
128 ksps ≤ symbol rate ≤ 10 Msps	Filtered OQPSK + NRZ-L	No	Code Rates ½, 2/3, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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[8]
64 ksps ≤ symbol rate ≤ 5 Msps	Filtered BPSK + NRZ-L	No			
64 ksps < symbol rate < 1.024Msps	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 using the 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] (CSP to Earth)					
Symbol Rates[1, 10]	**Modulation and Encoding[1, 10]**	**Ranging**	**Coding** LDPC[4]	**Space Data Link Protocol** AOS[3], USLP[5]	**Space Data link Security**
128ksps ≤ symbol rate ≤ 4 Msps[7]	Filtered OQPSK + NRZ-L	No	Code Rates ½, 2/3, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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[8]
64 ksps ≤ symbol rate ≤ 4 Msps[7]	Filtered BPSK + NRZ-L	No			
64 ksps < symbol rate ≤ 1.024Msps[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 using the 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: $\leq$ 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 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. 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. (401.0-B-31 will address higher PCM/PSK/PM symbol rates.)

3.2.2.2.1.1 FREQUENCY

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

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations.

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

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations.

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

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations.

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

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG and consistent with IOAG LCAWG draft recommendations.

Comm-14: Deleted

3.2.2.2.1.2 MODULATION ON THE COMMAND AND TELEMETRY LINK

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

Comm-15: CSP 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 CSP Command and Telemetry 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 Command and Telemetry 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: CSP-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 CSP Command and Telemetry 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 Command and Telemetry 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: CSP 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 CSP Command and Telemetry 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 Command and Telemetry link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between CSP 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-17: CSP-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 CSP Command and Telemetry 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 Command and Telemetry link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between CSP 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: CSP 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 CSP Command and Telemetry Link, and not exceeding subcarrier 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 Command and Telemetry link.

Rationale: PCM/PM/PSK with modulation on sub-carrier provides interoperability between CSP 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: CSP-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 CSP Command and Telemetry 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 Command and Telemetry link.

Rationale: PCM/PSK/PM with modulation on subcarrier provides interoperability between CSP 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 COMMAND AND TELEMETRY LINK

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

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

Rationale: CSP needs to be able to enable or disable FEC to support contingency and other operational scenarios.

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

Rationale: CSP needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-22: For symbol rates greater than 64 ksps, CSP shall use CCSDS Low Density Parity Codes, rate ½, rate 2/3, 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 CSP Command and Telemetry Link, on the Command and Telemetry 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, CSP-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate 2/3, 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 CSP Command and Telemetry Link, on the Command and Telemetry 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-24: For symbol rates less than or equal to 64 ksps, CSP-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 CSP Command and Telemetry Link, on the Command and Telemetry 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 CSP-Earth links. In order to reduce the burden on the links, we are using it over CSP-Ground-to-CSP links.

Comm-25: For symbol rates less than or equal to 64 ksps, CSP 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 CSP Command and Telemetry Link, on the Command and Telemetry link.

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

Comm-26: CSP 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 CSP-Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Command and Telemetry 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 CSP 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: CSP-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 CSP per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Command and Telemetry 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 CSP 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 $^2/_3$ LDPC Code*	*Rate $^4/_5$ LDPC Code*	*Rate $^7/_8$ LDPC Code*	*Uncoded*
ASM Length	64 bits	64 bits	64 bits	32 bits	32 bits
ASM Pattern (hex)	034776C7272895B0	034776C7272895B0	034776C7272895B0	1ACFFC1D	1ACFFC1D

Comm-28: CSP-Ground shall apply the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to CSP per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Command and Telemetry 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 CSP 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: CSP shall use the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames from CSP-Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the Command and Telemetry 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 CSP 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-30: CSP 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 CSP-Ground on the Command and Telemetry 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 CSP and NASA/International Partner ground stations.

Comm-31: CSP-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 CSP on the Command and Telemetry 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 CSP and NASA/International Partner ground stations.

Comm-32: CSP-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 CSP on the Command and Telemetry 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 CSP and NASA/International Partner ground stations.

Comm-33: CSP 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 CSP-Ground on the Command and Telemetry 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 CSP and NASA/International Partner ground stations.

Comm-34: When using BPSK, OQPSK and PCM/PSK/PM modulation schemes, CSP shall use NRZ-L encoding for transmission and reception of data streams to CSP-Ground on the Command and Telemetry 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 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, CSP-Ground shall use NRZ-L encoding for transmission and reception of data streams to CSP on the Command and Telemetry 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: CSP shall use the ASM for resolution of symbol phase ambiguity of received data streams from Ground on the Command and Telemetry 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: CSP-Ground shall use the ASM for resolution of symbol phase ambiguity of received data streams from CSP on the Command and Telemetry 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 COMMAND AND TELEMETRY LINK

Comm-38: Deleted

Comm-39: CSP shall use non-regenerative ranging with CSP-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 Command and Telemetry link.

Rationale: CSP needs to support radiometric tracking/ranging to support GN&C since there are currently no "Global Positioning System (GPS)" like capabilities. The ranging mode selected provides for simultaneous data with ranging.

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

Rationale: CSP needs 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: CSP-Ground shall support tracking as defined in CCSDS 503.0-B-1, Tracking Data Message, on the Command and Telemetry 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 COMMAND AND TELEMETRY LINK

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

Comm-43: CSP shall transmit data streams to CSP-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 CSP Command and Telemetry Link, on the Command and Telemetry 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 CSP 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.

Comm-44: CSP-Ground shall receive data streams from CSP 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 CSP Command and Telemetry Link, on the Command and Telemetry 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 CSP 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: CSP-Ground shall transmit data streams to CSP 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 CSP Command and Telemetry Link, on the Command and Telemetry 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 CSP 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: CSP shall receive data streams from CSP-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 CSP Command and Telemetry Link, on the Command and Telemetry 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 CSP 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.

3.2.2.2.1.6 NETWORK LAYERS AND ABOVE ON THE COMMAND AND TELEMETRY 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. CSP 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.

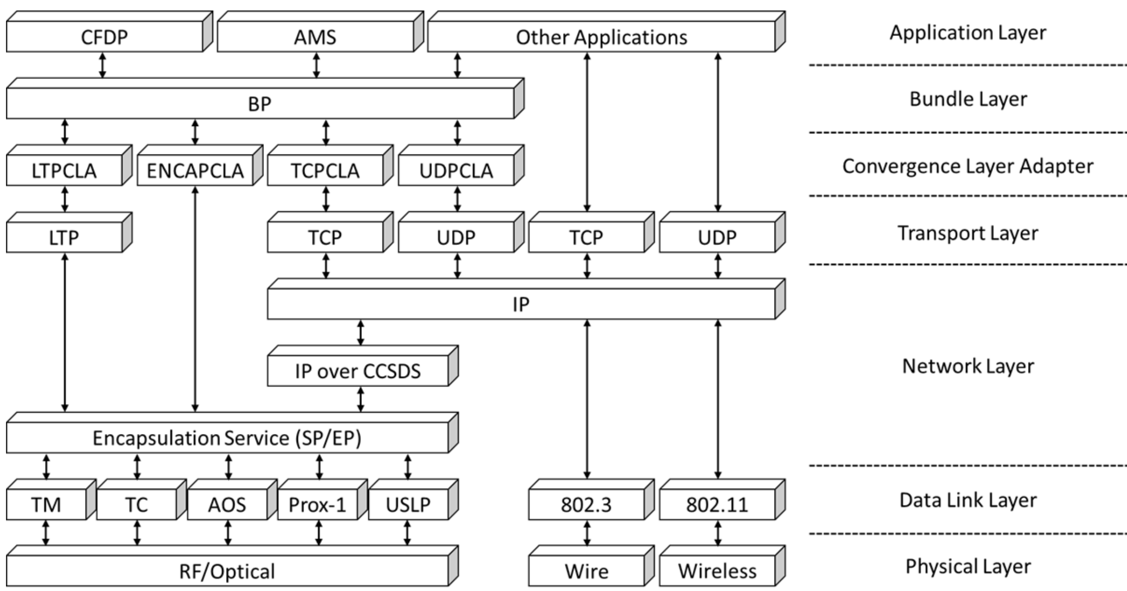


FIGURE 3.2.2.2.1.6-1 PROTOCOL STACK – OPTIONS

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.

3.2.2.2.1.6.1 NETWORK LAYER

Comm-47: CSP 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 CSP-Ground on the Command and Telemetry 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: CSP-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 CSP on the Command and Telemetry 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: CSP 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 CSP-Ground MOC/MCC on the Command and Telemetry link.

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

Comm-50: CSP-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 CSP on the Command and Telemetry link.

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

Comm-51: CSP shall use IP as specified in Internet Protocol version 4 (IPv4) (RFC 791, Internet Protocol) or IPv6 (RFC 8200, Internet Protocol, Version 6 (IPv6) Specification) **<TBR 3-16>** as a network layer with CSP-Ground MOC/MCC on the Command and Telemetry link.

*Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec **<TBD 3-9>**) 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 CSP-Ground can be the ground station or the ground station and MOC/MCC, the IP protocol functions are usually between CSP and MOC/MCC and not at the ground stations.*

Comm-52: CSP-Ground MOC/MCC shall use IP as specified in IPv4 (RFC 791, Internet Protocol) or IPv6 (RFC 8200, Internet Protocol, Version 6 (IPv6) Specification) **<TBR 3-16>** as a network layer with CSP on the Command and Telemetry link.

*Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec **<TBD 3-9>**) 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 CSP-Ground can be the ground station or the ground station and MOC/MCC, the IP protocol functions are usually between CSP and MOC/MCC and not at the ground stations.*

3.2.2.2.1.6.2 TRANSPORT LAYER

Comm-53: CSP 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 Command and Telemetry 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: CSP shall implement Transmission Control Protocol (TCP) as specified in RFC 793, Transmission Control Protocol, on the Command and Telemetry link.

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

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

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

3.2.2.2.1.6.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-56: CSP shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the Command and Telemetry 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 CSP must have the capability to multiplex/demultiplex multiple data streams from multiple sources over heterogeneous links.

Comm-57: DELETED

Comm-58: CSP should **<TBR 3-19>** 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 CSP-Ground can be the ground station or the ground station and MOC/MCC, the IP protocol functions are usually between CSP and MOC/MCC and not at the ground stations.

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

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 ***<TBR 3-28>****.*

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

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

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

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 Command and Telemetry 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-64: CSP 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 Command and Telemetry 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 CSP partners implement these options.

Comm-65: CSP 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 Command and Telemetry 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 COMMAND AND TELEMETRY LINK

The following requirements define the security standards to ensure interoperability for the Command and Telemetry CSP to CSP-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: CSP shall implement CCSDS Cryptographic Algorithms, CCSDS 352.0-B-1, Advanced Encryption Standard (AES), for encryption/decryption of data exchanges with CSP-Ground on the Command and Telemetry link.

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

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

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

Comm-68: CSP 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 CSP-Ground on the Command and Telemetry 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: CSP-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 CSP on the Command and Telemetry 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 MOU/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. While CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

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

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-71: CSP-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 CSP on the Command and Telemetry link.

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

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

Rationale: CSP needs to support authentication in addition to encryption.

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

Rationale: CSP needs to support authentication in addition to encryption. While CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

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

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

Comm-75: CSP-Ground MOC/MCC shall be able to enable or disable encryption to support contingency operations with CSP on the Command and Telemetry link.

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

Comm-76: CSP shall employ key management techniques as defined in **<TBD 3-1>** with CSP-Ground on the Command and Telemetry 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 is working on the Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. Once the standard is baselined and all partners agree to implement it, the requirement will be updated.

Comm-77: CSP-Ground MOC/MCC shall employ key management techniques as defined in **<TBD 3-1>** with CSP on the Command and Telemetry 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 CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Note: CCSDS is working on the Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. Once the standard is baselined and 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 CSP and CSP-Ground. Ka-band and Optical communication links are selected for this application. Ka-band is considered for CSP 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 Command and Telemetry link supports the ranging needs on CSP.

NASA and International Partner ground stations currently only support Ka-band downlink and do not provide Ka-band uplink capability since it has not been needed, so far, for deep space science and robotic missions. It is expected that CSP 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. NASA is expanding the DSN by adding new 34m beam wave-guide (BWG) antennas and the NEN with new 18m antennas both of which are equipped with Ka-band uplink capability with planned implementation in time to support CSP.

A minimum set of standards for the Ka-band uplink is also included in this section to provide the implementers some guidance on what a Ka-band forward link might support. These uplink standards are marked with a TBR to indicate that they still need to be finalized.

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 as well as providing both a high rate uplink and downlink. An optical link between CSP and Earth is planned to support CSP utilization needs. This communication link will first be used to demonstrate and validate some of the optical communication technologies and then will become operational.

3.2.2.2.2.1 HIGH RATE RF LINK

The required standards for the CSP to CSP-Ground high rate RF link is provided in Table 3.2.2.2-3, Required Standards for CSP High Rate RF Link.

TABLE 3.2.2.2-3 REQUIRED STANDARDS FOR CSP HIGH RATE RF LINK

Ka-band Forward Link (22.55 - 23.15 GHz)[6] (Earth to CSP)					
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**
2 Msps ≤ symbol rate (Target rates are ~ 50 Msps)	Filtered OQPSK + NRZ-L	No	Code Rates ½, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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]
Ka-band Return Link (25.5 GHz – 27.0 GHz)[6] (CSP to Earth)					
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**
2 Msps ≤ symbol rate (Target rates are ~200Msps)	Filtered OQPSK + NRZ-L	No	Code Rates ½, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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. 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. CCSDS 401.0-B-30 Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft, Blue Book. (401.0-B-31 will address higher PCM/PSK/PM symbol rates.)

3.2.2.2.2.1.1 FREQUENCY FOR HIGH RATE RF LINKS

Comm-78: CSP shall use 25.5 - 27 gigahertz (GHz) (Ka-band) frequency band to transmit signals to CSP-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.

Comm-79: CSP-Ground shall use 25.5 - 27 GHz (Ka-band) frequency band to receive signals from CSP 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.

Comm-80: CSP-Ground shall use 22.55 – 23.15 GHz (Ka-band) frequency band to transmit signals to CSP 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.

Comm-81: CSP shall use 22.55 – 23.15 GHz (Ka-band) frequency band to receive signals from CSP-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.

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 CSP High Rate RF Link, and expanded in this section.

Comm-82: CSP shall implement filtered OQPSK to transmit signals to CSP-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 provides spectral efficiency and interoperability between CSP 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: CSP-Ground shall implement filtered OQPSK to receive signals from CSP 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 CSP 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: CSP-Ground shall implement filtered OQPSK to transmit signals to CSP 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. **<TBR 3-15>**

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between CSP 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: CSP shall implement filtered OQPSK to receive signals from CSP-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. **<TBR 3-15>**

Rationale: Filtered OQPSK carrier provides spectral efficiency and interoperability between CSP 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.

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 CSP High Rate RF Link, and expanded in this section.

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

Rationale: CSP needs to be able to enable or disable FEC to support contingency and other operational scenarios.

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

Rationale: CSP needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-86: CSP shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, or rate $^{7}/_{8}$ for encoding data to CSP-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 CSP 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: CSP-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for decoding data from CSP 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 CSP 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-88: CSP-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for encoding data to CSP 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 CSP High Rate RF, on the High Rate RF link. **<TBR 3-15>**

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 CSP-Earth links. In order to reduce the burden on the links, we are using it over CSP-Ground-to-CSP links.

Comm-89: CSP shall use CCSDS Low Density Parity Codes, rate ½, rate $^2/_3$, rate $^4/_5$, or rate $^7/_8$ for decoding data from CSP-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 CSP 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: CSP shall apply the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to CSP-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, 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 CSP 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: CSP-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 CSP 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, 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 CSP 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: CSP-Ground shall apply the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, to transmitted frames to CSP per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the High Rate RF link. **<TBR 3-15>**

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 CSP 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: CSP shall use the ASM defined in CCSDS 131.0-B-3, TM Synchronization and Channel Coding, Section 9, for synchronization of received frames from CSP-Ground per Table 3.2.2.2-2, ASM for Selected LDPC Codes, on the High Rate RF link. **<TBR 3-15>**

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 CSP 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: CSP 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 CSP-Ground 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 CSP and NASA/International Partner ground stations.

Comm-95: CSP-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 CSP 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 CSP and NASA/International Partner ground stations.

Comm-96: CSP-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 CSP on the High Rate RF link. **<TBR 3-15>**

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 CSP and NASA/International Partner ground stations.*

Comm-97: CSP 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 CSP-Ground on the High Rate RF link. **<TBR 3-15>**

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 CSP and NASA/International Partner ground stations.

Comm-98: CSP shall use NRZ-L encoding for transmission of data streams to CSP-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: CSP-Ground shall use NRZ-L encoding for transmission of data streams to CSP on the High Rate RF link. **<TBR 3-15>**

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-100: CSP shall use the ASM for resolution of symbol phase ambiguity of received data streams from CSP-Ground on the High Rate RF link. **<TBR 3-15>**

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: CSP-Ground shall use the ASM for resolution of symbol phase ambiguity of received data streams from CSP 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 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 CSP High Rate RF Link, and expanded in this section.

Comm-102: CSP 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 CSP High Rate RF Link, to CSP-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 CSP 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-103: CSP-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 CSP High Rate RF Link, from CSP 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 CSP and NASA/International Partner ground stations.

Note: CCSDS is 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-104: CSP-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 CSP High Rate RF Link, to CSP on the High Rate RF link. **<TBR 3-15>**

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 CSP 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: CSP 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 CSP High Rate RF Link, from CSP-Ground on the High Rate RF link. **<TBR 3-15>**

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 CSP and NASA/International Partner ground stations.

Note: CCSDS recently 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.

3.2.2.2.2.1.5 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.

3.2.2.2.2.1.5.1 NETWORK LAYER

Comm-106: CSP shall transmit and receive **<TBR 3-15>** 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 CSP-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: CSP-Ground shall transmit **<TBR 3-15>** 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 CSP 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: CSP shall transmit and receive **<TBR 3-15>** 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 CSP-Ground MOC/MCC on the High Rate RF link.

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

Comm-109: CSP-Ground MOC/MCC shall transmit **<TBR 3-15>** 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 CSP on the High Rate RF link.

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

Comm-110: CSP shall use IP as specified in IPv4 (RFC 791, Internet Protocol) or IPv6 (RFC 8200, Internet Protocol, Version 6 (IPv6) Specification) **<TBR 3-16>** as a network layer with CSP-Ground on the High Rate RF link.

*Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec **<TBD 3-9>**) 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: CSP-Ground shall use IP as specified in IPv4 (RFC 791, Internet Protocol) or IPv6 (RFC 8200, Internet Protocol, Version 6 (IPv6) Specification) **<TBR 3-16>** as a network layer with CSP on the High Rate RF link.

*Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec **<TBD 3-9>**) 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.*

3.2.2.2.2.1.5.2 TRANSPORT LAYER

Comm-112: CSP 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: CSP 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: CSP 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.

3.2.2.2.2.1.5.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-115: CSP 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 CSP must have the capability to multiplex/demultiplex multiple data streams from multiple sources over heterogeneous links.

Comm-116: DELETED

Comm-117: CSP should **<TBR 3-19>** 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: CSP 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 **<TBR 3-28>**.*

Comm-119: CSP 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.

Comm-120: CSP 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.

Comm-121: CSP 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.

3.2.2.2.2.1.5.4 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: CSP 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 CSP partners implement these options.

Comm-124: CSP 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.

3.2.2.2.2.1.6 SECURITY ON HIGH RATE RF LINKS

The following requirements define the security standards to ensure interoperability for the High Rate RF CSP to CSP-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: CSP 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 CSP-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: CSP-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 CSP 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 CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Comm-127: CSP 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 CSP-Ground on the High Rate RF 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 MOU/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-128: CSP-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 CSP on the High Rate RF 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 MOU/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. While CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

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

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-130: CSP-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 CSP on the High Rate RF link.

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

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

Rationale: CSP needs to support authentication in addition to encryption.

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

Rationale: CSP needs to support authentication in addition to encryption. While CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations

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

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

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

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

Comm-135: CSP shall employ key management techniques as defined in **<TBD 3-1>** with CSP-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 is working on the Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. Once the standard is baselined and all partners agree to implement it, this requirement will be updated.

Comm-136: CSP-Ground MOC/MCC shall employ key management techniques as defined in **<TBD 3-1>** with CSP 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 CSP-Ground can be the ground station or the ground station and MOC/MCC, the encryption/decryption and authentication functions are usually performed at the MCC/MOC and not at the ground stations.

Note: CCSDS is working on the Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. Once the standard is baselined and all partners agree to implement it, this requirement will be updated.

3.2.2.2.2.2 OPTICAL LINKS

Optical links between CSP and Earth will be used to validate performance and extensibility to deep space as well as to augment/provide higher rate links for CSP and CSP 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 CSP to Earth trunk lines, CSP to lunar surface, and CSP to nearby spacecraft; basically for all optical links in the lunar vicinity. The draft HPE recommendations are documented in CCSDS 141.0-R-1, Optical Communications Physical Layer, Red Book, dated April 10, 2018, and in CCSDS 141.1-R-1-v10, Optical Communications Coding and Synchronization, Red Book, dated April 25, 2018. These books define the downlink and uplink optical waveforms, coding, and synchronization. The Red Books will become recommended standards (Blue Books) once two independent prototypes have been developed and verified. Once CCSDS issues Blue Books for High Photon Efficiency, this section will be updated to include the relevant standard and specifications.

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

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. 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 ranging 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 the CSP, 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 CSP is uncrewed, a low-rate uplink is sufficient to command the CSP. Once the recommended standards and protocols have been agreed to by the partners, this section will be updated with the corresponding detailed requirements.

TABLE 3.2.2.2-4 DRAFT REQUIRED STANDARDS FOR CONTINGENCY COMMUNICATION LINK

X-band Forward Link (7190-7235 MHz)[6] (Earth to CSP) 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] (CSP 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. (401.0-B-31 will address higher PCM/PSK/PM symbol rates.)

3.2.2.3 CSP – VV COMMUNICATION LINKS

CSP to VV link is the Space-to-Space link between CSP and visiting vehicles such as Orion, logistics modules, or another CSP, etc. The VV will rendezvous and dock/berth to the CSP. The CSP to 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 CSP. The detailed breakdown of data transferred between CSP and a VV is given in Appendix D.

The CSP-VV S-band link is designed to support Space-to-Space radiometric tracking to provide range and range rate measurements. The system, in Point B mode, generates, modulates, and transmits the range channel data; and it receives and processes the coherent turn-around ranging channel and carrier to obtain the range and range-rate measurements. The system, in Point A mode, coherently retransmits the received carrier and range channel to support radiometric measurements. Once docked to CSP, the VV will have a hardline interface with the CSP via a docking system. This hardline interface will be used to transfer data between the VV and CSP as defined in IASIS.

Example use case: The Orion S-band system can support both Point A and Point B mode. In this example, the S-band system on the Orion is in Point B mode and the CSP is in Point A mode. Orion generates, modulates, and transmits the ranging channel; the CSP 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 CSP, Orion will use the hardline interface with CSP via the docking system to exchange data with the CSP, and Orion data will be relayed by the CSP to/from Earth.

The CSP could choose to implement the Point A side, the Point B side or both. If the CSP implements the Point A side, than the VV must implement the Point B side; if the CSP implements the Point B side, the VV must implement the Point A side. If the CSP implements both, 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 CSP – VV 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 CSP and which one is the VV. The CSP requirements and respective IRDs, in coordination with the VVs will define the roles of Point A/B.

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 CSP-VV Interface Requirements Documents (IRDs).

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 CSP- VV Interface Requirements Documents (IRDs).

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.

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.

3.2.2.3.2 MODULATION AND SIGNAL CHARACTERISTICS ON CSP – VV 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 CSP and which one is the VV. The CSP requirements and respective IRDs will define the roles of Point A/B.

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 CSP – VV 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 CSP – VV links.

Rationale: Non-coherent operation is required in order that Point A side can deliver telemetry and permit tracking to be performed 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 CSP – VV 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 range rate data for the CSP – VV links.

Rationale: The Point B vehicle should measure one-way range rate (non-coherent Point A) or two-way range rate (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 CSP – VV 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 CSP-Visiting Vehicle 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 CSP-Visiting Vehicle 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.

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 CSP-VISITING VEHICLE 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 CSP-Visiting Vehicle 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-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 CSP-Visiting Vehicle 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 CSP-VISITING VEHICLE 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 CSP – VV LINK

Comm-156: CSP shall transmit using right hand circular polarization on CSP to VV links.

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

Comm-157: CSP shall receive using right hand circular polarization on VV to CSP links.

Rationale: RHCP is selected to be compatible with Orion.

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

Rationale: RHCP is selected to be compatible with Orion.

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

Rationale: RHCP is selected to be compatible with Orion.

3.2.2.3.4 CODING AND SYNCHRONIZATION ON CSP – VV LINK

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

Comm-160: CSP 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 CSP – VV 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-161: CSP 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 CSP – VV 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: CSP and VV shall enable and disable communication link FEC on CSP-VV links upon receipt of command.

Rationale: CSP needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-163: CSP 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 CSP – VV 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 CSP 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: CSP 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 CSP-VV 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 CSP 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: CSP 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 CSP-VV links.

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 CSP and VV.

Comm-166: CSP 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 CSP-VV 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 CSP and VV.

Comm-167: CSP and VV shall use NRZ-L encoding for transmission of data streams on CSP-VV 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: CSP 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 CSP – VV LINK

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

Comm-169: CSP 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 CSP-VV 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 CSP and VV.

Comm-170: CSP 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 CSP-VV 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 CSP and VV.

Comm-171: CSP 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 CSP-VV links.

Rationale: Required for compatibility with Orion.

The protocol stack for coded CSP-VV 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 CSP-VV 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.

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

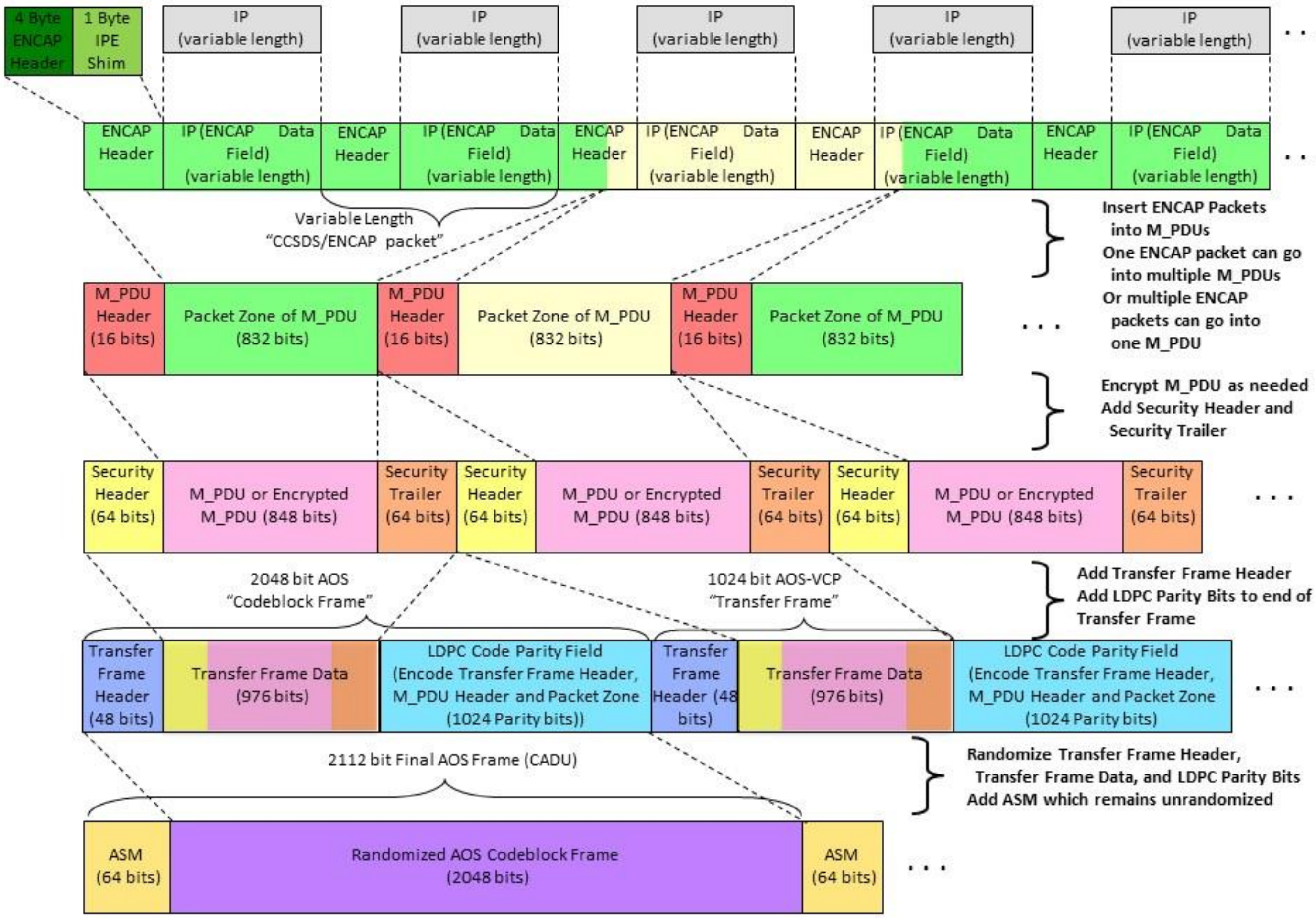


FIGURE 3.2.2.3-1 PROTOCOL STACK FOR RATE ½ LDPC CODED LINKS

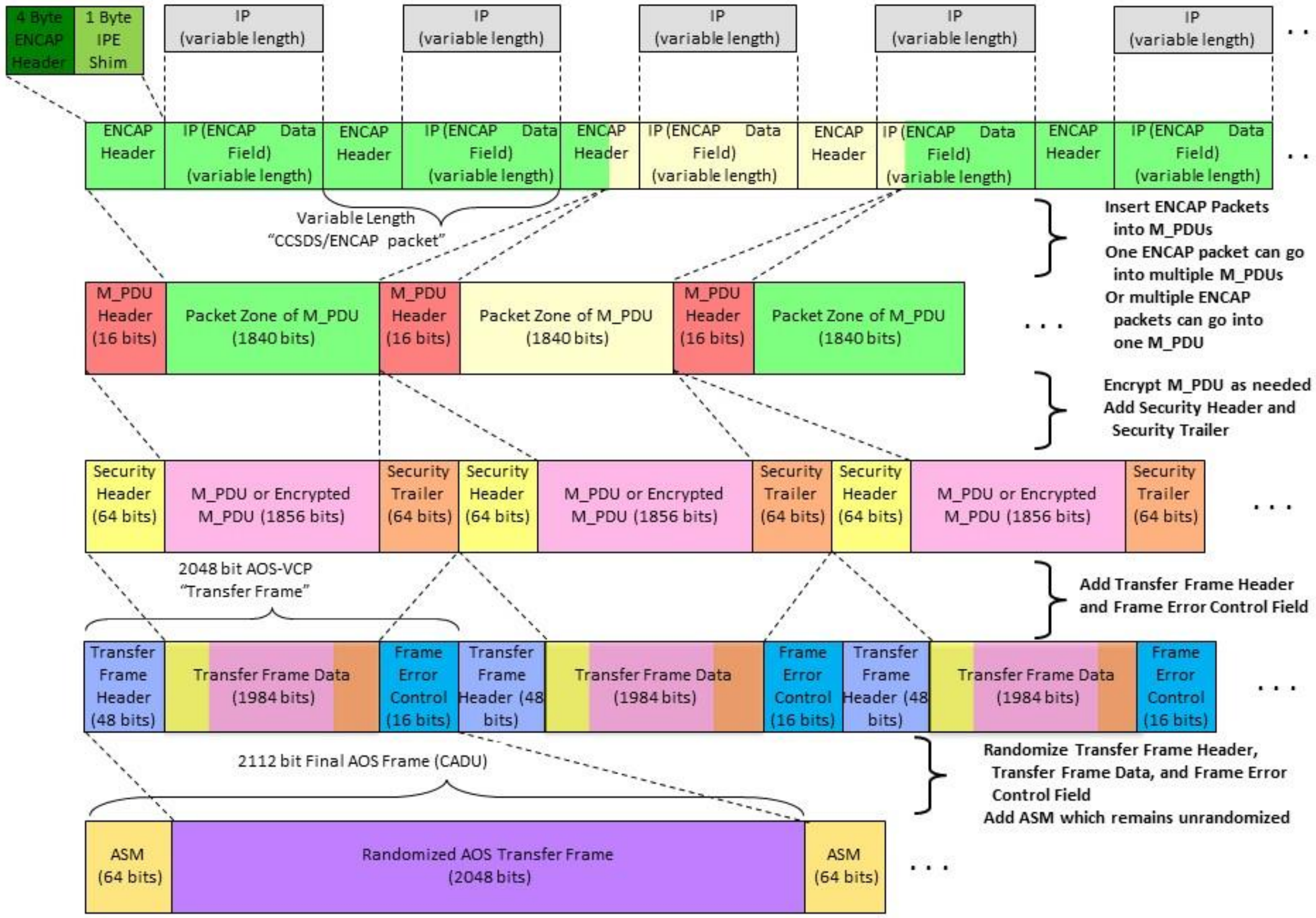


FIGURE 3.2.2.3-2 PROTOCOL STACK OPTION FOR UNCODED LINKS

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 CSP –VV interface).

Comm-172: CSP and VV shall use CCSDS File Delivery Protocol as defined in CCSDS 727.0-B-4, CCSDS File Delivery Protocol (CFDP), January 2007, on CSP-VV links.

Rationale: Provide reliable, accountable transfer of application data between the end nodes or between 2 nodes over point-to-point space link.

Comm-173: CSP 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 CSP-VV 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: CSP – VV links should **<TBR 3-19>** 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

Comm181: DELETED

Comm-182: DELETED

Comm-183: DELETED

3.2.2.3.7 SECURITY ON CSP – VV LINK

Comm-234: CSP and VV shall be able to enable or disable encryption to support contingency operations.

Rationale: CSP and VV needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

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

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

Comm-186: CSP and VV shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol, on CSP-VV links.

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

3.2.2.4 PROXIMITY COMMUNICATIONS: CSP – EVA COMMUNICATIONS LINK

There will be CSP based EVAs for surface operations, and to support contingencies and/or emergencies around CSPs in cislunar orbit. The current CSP habitation systems and landing/ascent systems are being designed to accommodate a maximum of 4 EVA crew members. The CSP will relay the EVA data to/from Earth. When there are crewed lunar surface operations, the EVAs will be based off of the landed CSP, 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 CSP or rover/habitat. The landed CSP or the rover/habitat will relay EVA data to/from Earth and/or orbiting CSP. Note: there could be CSPs in cislunar orbit and other CSPs that transition from cislunar orbit to the lunar surface and transition back from lunar surface to cislunar orbit. During EVAs around orbiting CSPs, there will be 2 EVA crew members outside the CSP. There will be no EVAs on orbiting CSPs 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). The current plan is for EVAs using the same communications hardware for CSP 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 CSP and EVAs (including EVA-EVA communications). The same set of standards and protocols will be used for EVA-Rover/habitat communications on lunar surface. The next section, 3.2.2.5, will address the non-critical, high rate communications between CSP and EVAs (including EVA-EVA communications) as well as other users and applications. The following requirements apply to CSPs both in orbit and on the lunar surface.

3.2.2.4.1 CSP – EVA COMMUNICATIONS – FREQUENCY, NUMBER OF USERS

Comm-187: CSP 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 CSP.

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-189: CSP – 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 landed CSP/rover/habitation the lunar surface; 2 EVAs, a landed CSP, a rover and a habitat, etc.). The EVA crew members need to be able to communicate with each other and the landed CSP/rover/habitat. There may be cases where surface EVA is scheduled at the same time an EVA is occurring on an orbiting CSP. 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 CSP – EVA COMMUNICATION LINK – SIGNAL CHARACTERISTICS

Comm-247: CSP – 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.

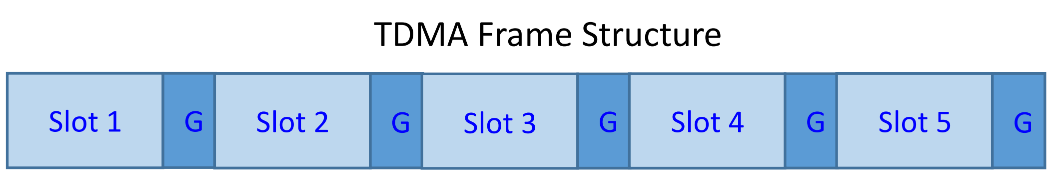
<TBD 3-2> (defining standards for coding, etc. is forward work)

3.2.2.4.3 CSP – 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: CSP – 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 CSP-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.



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

Figure 3.2.2.4.3 CSP-EVA Communication Link TDMA Frame Structure

3.2.2.4.4 CSP – EVA COMMUNICATIONS: SECURITY

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

3.2.2.5 CSP – WIRELESS COMMUNICATION LINKS

This section defines the protocols and standards for wireless communications. Wireless communication networks provides communications within the CSP as well as external to the CSP in cislunar orbit as well as on the lunar surface. CCSDS is working on a wireless proximity network communications standard (CCSDS 883-0). Once that standard is approved and agreed to by the partners, it will be included in this section. 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, etc.). Wireless communications will be used to exchange non-critical, high rate communications between CSP and EVAs (including EVA-EVA communications). The wireless communications between CSP and VV could also be used to transfer non-critical imagery during RPOD when the VV is within wireless communication range to CSP. As mentioned previously, there would be no nominal EVAs during RPOD activities.

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

Comm-191: CSP wireless systems shall use the following numerated standards for wireless communications:

1. Access point(s) supporting clients conforming to version Institute of Electrical and Electronics Engineers (IEEE) 802.11n in the 2.4 GHz unlicensed band to provide wireless network extension inside and outside the CSP. Operational constraints can be used to mitigate any interference issues caused by the use of 2.4 GHz band for external wireless communications during CSP-VV rendezvous, proximity operations and docking.
2. Access point(s) supporting clients conforming to versions IEEE 802.11n and 802.11ac in the 5 GHz unlicensed band to provide wireless network extension inside and outside the CSP.
3. RFID based systems shall follow the protocols and standards provided in CCSDS 881.0-M-1, Spacecraft Onboard Interface Services – RFID Based Inventory Management Systems, to provide RFID services within the CSP.
4. 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 CSP.

5. RFID based systems shall support tags conforming to **<TBD 3-6>** to provide RFID services inside the CSP. (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).
6. CSP for 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 CSP.
7. Access point(s) supporting clients conforming to at least version IEEE 802.11ah **<TBR 3-12>** in the 900 MHz unlicensed band to provide wireless network extension outside the CSP.
8. Long Term Evolution (LTE) eNodeB(s) supporting User Equipment (UE) conforming to Release 13 **<TBR 3-13>** in a licensed band to provide CSP network extension inside and outside the CSP.

Rationale: The identified standards IEEE 802.11n/ac, 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 CSP begins. LTE can be deployed in licensed bands and has more evolved Quality of Service controls and therefore can be offered to critical applications. Products are available which support the wireless standards, and wired cameras or other sensors can also be integrated with wireless peripherals.

3.2.2.6 CSP – LUNAR SYSTEM COMMUNICATION LINKS

This section captures the standards and protocols for communications between the CSP and systems in lunar orbit, lunar vicinity (example – transitioning between NHRO to Lunar surface) or on the lunar surface. The CSP-Lunar System link will be used to communicate with lunar systems and, in conjunction with the CSP-Earth link, be used to relay data between the Earth and lunar systems. In addition, the CSP-Lunar surface link could be used to “tele-operate” lunar surface robotic systems. CSP – Lunar 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 LCAWG, NASA and International Partners. The architecture adopted for the CSP to Lunar Systems communications is consistent with the IOAG LCAWG’s draft study recommendations, and complies with Rec. ITU-R RA.479-5. As CSP gets assembled and additional capabilities are added to and expected from CSP, the CSP-Lunar systems communications link will support crewed lunar missions, Lunar ascenders and descenders from CSP, additional science, etc. CSP – 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 CSP supports the lunar system's need for radiometric tracking and data exchange with CSP, thus providing communications and radiometric tracking to ascenders, descenders, etc., all the way from CSP to the Lunar surface and back. In these scenarios, we can have orbiting CSPs, CSPs that are transiting to/from Orbit to the lunar surface, landed CSPs and deployed CSPs. The transiting, landed, and deployed CSPs are considered the "Lunar Systems" side in the following requirements and will be communicating with an orbiting CSP.

Example use case: The Gateway – HLS Conops: Gateway and HLS are both CSPs. The HLS will communicate with 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 is an orbiting CSP. The HLS will come in, rendezvous and dock with Gateway. In this mission phase, HLS is a "VV" CSP and will communicate with Gateway over the Gateway – VV link.*
- *The HLS will take crew from Gateway, undock and move away from Gateway. Gateway is the CSP. During this phase, Gateway is an orbiting CSP and HLS is again a "VV" CSP and will communicate over the Gateway-VV link.*
- *After HLS transits further away from Gateway (range TBD), it is "Lunar System" CSP – 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 CSP - Lunar Systems link.*
- *When HLS starts the RPOD activities, it is back in VV mode and will communicate with Gateway over the CSP – VV link..*

The following sections contain the required standards and protocols for the CSP - Lunar Systems links, and are summarized in Table 3.2.2.6-1, Required Standards for CSP – Lunar Systems RF Links.

TABLE 3.2.2.6-1 REQUIRED STANDARDS FOR CSP – LUNAR SYSTEMS RF LINKS (PAGE 1 OF 2)

S-band Forward Link (2025-2110 MHz)[6] (CSP 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**
1 Msps ≤ symbol rate < 6 Msps	Filtered BPSK/BPSK + NRZ-L	No	Code Rates ½, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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 ksps ≤ symbol rate < 1 Msps	Filtered BPSK/BPSK + NRZ-L	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 (modulation on residual carrier)	Yes[2]			
0.5 ksps ≤ symbol rate ≤ 48 ksps	PCM/PSK/PM + NRZ-L (modulation on subcarrier)	Yes[2]			

Ka-band Forward Link (23.15-23.55 GHz)[6] (CSP 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**
1 Msps ≤ symbol rate	Filtered OQPSK + NRZ-L	No	Code Rates ½, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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. (401.0-B-31 will address higher PCM/PSK/PM symbol rates.

TABLE 3.2.2.6-1 REQUIRED STANDARDS FOR CSP – LUNAR SYSTEMS RF LINKS (PAGE 2 of 2)

S-band Return Link (2200-2290 MHz)[6] (Lunar Systems to CSP)

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 Msps ≤ symbol rate < 6 Msps	Filtered BPSK/BPSK + NRZ-L	No	Code Rates ½, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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 ksps ≤ symbol rate ≤ 1 Msps	Filtered BPSK/BPSK + NRZ-L	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 (modulation on residual carrier)	Yes[2]			
0.5 ksps ≤ symbol rate ≤ 48 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 CSP)

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 Msps ≤ symbol rate	Filtered OQPSK + NRZ-L	No	Code Rates ½, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$, 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) • 3072 octets plus 64 bit ASM (for rate ⅔) • 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. (401.0-B-31 will address higher PCM/PSK/PM symbol rates.

3.2.2.6.1 FREQUENCY FOR CSP-LUNAR SYSTEM LINK

Ka-band and S-band are selected for the CSP-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: CSP shall use 23.15 – 23.55 GHz frequency band to transmit signals to the lunar system element on the CSP-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.

Comm-193: Lunar system element shall use 23.15 – 23.55 GHz frequency band to receive signals from the CSP on the CSP-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.

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

Comm-195: CSP shall use 27.0 – 27.5 GHz frequency band to receive signals from the lunar system element on the CSP-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.

Comm-235: CSP shall use 2.025 – 2.110 GHz frequency band to transmit signals to the lunar system element on the CSP-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.

Comm-236: Lunar system element shall use 2.025 – 2.110 GHz frequency band to receive signals from the CSP on the CSP-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.*

Comm-237: CSP shall use 2.200 – 2.290 GHz frequency band to receive signals from the lunar system element on the CSP-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.

Comm-238: Lunar system element shall use 2.200 – 2.290 GHz frequency band to transmit signals to the CSP on the CSP-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.

3.2.2.6.2 MODULATION FOR THE CSP – LUNAR SYSTEM LINK

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

Comm-196: CSP 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 CSP-Lunar System high rate, Ka-band link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between CSP and/International Partner 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 CSP as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the CSP-Lunar System high rate, Ka-band link.

Rationale: Filtered OQPSK provides spectral efficiency and interoperability between CSP 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 CSP as described in CCSDS 401.0-B-30, Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, on the CSP-Lunar System high rate, Ka-band link.

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

Comm-197: CSP 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 CSP-Lunar System high rate, Ka-band link.

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

Comm-243: CSP shall implement filtered BPSK/BPSK for symbol rates within the ranges defined in Table 3.2.2.6-1, Required Standards for CSP – 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 CSP-Lunar System low rate, S-band link.

Rationale: Filtered BPSK/BPSK provides interoperability between CSP 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 3.2.2.6-1, Required Standards for CSP – 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 CSP-Lunar System low rate, S-band link.

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

Comm-245: CSP shall implement PCM/PM/Bi-phase-L with modulation on residual carrier for symbol rate within the ranges defined in Table 3.2.2.6-1, Required Standards for CSP – 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 CSP-Lunar System low rate, S-band link.

Rationale: PCM/PM/Bi-phase-L with modulation on residual carrier provides interoperability between CSP 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 3.2.2.6-1, Required Standards for CSP – 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 CSP-Lunar System low rate, S-band link.

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

Comm-248: CSP shall implement PCM/PSK/PM with modulation on the subcarrier for symbol rate within the ranges defined in Table 3.2.2.6-1, Required Standards for CSP – 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 CSP-Lunar System low rate, S-band link.

Rationale: PCM/PSK/PM with modulation on the subcarrier provides interoperability between CSP 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 3.2.2.6-1, Required Standards for CSP – 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 CSP-Lunar System low rate, S-band link.

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

3.2.2.6.3 CODING AND SYNCHRONIZATION FOR THE CSP – LUNAR SYSTEM LINK

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

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

Rationale: CSP needs to be able to enable or disable FEC to support contingency and other operational scenarios.

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

Rationale: Lunar System element needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-198: CSP 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 CSP – Lunar Systems RF Links, on the CSP-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-199: CSP 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 CSP – Lunar Systems RF Links, on the CSP-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, CSP 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 CSP – Lunar Systems RF Links, on the CSP-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, CSP 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 3.2.2.6-1, Required Standards for CSP – Lunar Systems RF Links, on the CSP-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, CSP 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 CSP – Lunar Systems RF Links, on the CSP-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-253: For symbol rates less than or equal to 1.024 Msps, CSP 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 CSP – Lunar Systems RF Links, on the CSP-Lunar System low rate S-band link.

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

Comm-200: CSP 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 CSP-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 CSP 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: CSP 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 CSP-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 CSP 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: CSP 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 CSP-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 CSP and NASA/International Partner assets.

Comm-203: CSP 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 CSP-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 CSP and NASA/International Partner assets.

Comm-204: When using BPSK/filtered BPSK, and PCM/PSK/PM modulation schemes, CSP and lunar system element shall use NRZ-L encoding for transmission of data streams on the CSP-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: CSP and lunar system element shall use the ASM for resolution of symbol phase ambiguity of received data streams on the CSP-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 CSP – LUNAR SYSTEM LINK

Comm-242: CSP 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 CSP-Lunar System link.

Rationale: CSP and Lunar elements needs 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.

3.2.2.6.5 DATA LINK FOR THE CSP – LUNAR SYSTEM LINK

Comm-206: CSP 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 CSP – Lunar Systems RF Links, on the CSP-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 CSP 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: CSP 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 CSP – Lunar Systems RF Links, on the CSP-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 CSP 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.

3.2.2.6.6 NETWORK LAYERS AND ABOVE FOR THE CSP – LUNAR SYSTEM LINK

3.2.2.6.6.1 NETWORK LAYER

Comm-208: CSP 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 CSP-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: CSP 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 CSP-Lunar System link.

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

Comm-210: CSP and lunar system element shall use IP as specified in IPv4 (RFC 791, Internet Protocol) or IPv6 (RFC 8200, Internet Protocol, Version 6 (IPv6) Specification) **<TBR 3-16>** as a network layer on the CSP-Lunar System link.

*Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec **<TBD 3-9>**) 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: CSP 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 CSP-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: CSP and lunar element shall implement TCP as specified in RFC 793, Transmission Control Protocol, on the CSP-Lunar System link.

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

Comm-213: CSP and lunar system element shall implement UDP as specified in RFC 768, User Datagram Protocol, on the CSP-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: CSP and lunar element shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the CSP-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 CSP must have the capability to *multiplex/demultiplex multiple data streams from multiple sources over heterogeneous links.*

Comm-215: **DELETED**

Comm-216: CSP and lunar elements should **<TBR 3-19>** 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: CSP 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 CSP-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 ***<TBR 3-28>****.*

Comm-218: CSP and lunar element shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the CSP-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.

Comm-219: CSP 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 CSP-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.

Comm-220: CSP and lunar element should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1, CCSDS Bundle Protocol Specification, on the CSP-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.

3.2.2.6.6.4 APPLICATION LAYER

Comm-221: All applications transferring data over the CSP - lunar system element interface shall use either DTN Bundle Protocol or IP as specified above on the CSP-Lunar System 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-222: CSP 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 CSP-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 CSP partners implement these options.

Comm-223: CSP 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 CSP-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 CSP – 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: CSP 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 CSP-Lunar System link.

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

Comm-225: CSP 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 CSP-Lunar System 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 MOU/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-226: CSP 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 CSP-Lunar System link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-227: CSP 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 CSP-Lunar System link.

Rationale: CSP needs to support authentication in addition to encryption.

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

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

Comm-229: CSP and lunar system elements shall employ key management techniques as defined in **<TBD 3-1>** on the CSP-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 is working on the Draft CCSDS 355.1-B-1, Space Data Link Security (SDLS) Extended Procedures. Once the standard is baselined and all partners agree to implement it, this requirement will be updated.

3.2.2.7 LANDED / DEPLOYED CSP – LUNAR SURFACE COMMUNICATIONS (IN WORK)

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. A UHF-band system is used for core 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 2.4 GHz band allocated to Wi-Fi communications. The wireless standards are given in Section 3.2.2.2.5 CSP-Wireless Communication Links. As LTE and other technology matures and is validated for space use, these standards will be updated to include these capabilities. The types of data transferred over these links will be quite diverse ranging from high-definition videos, rover status and engineering telemetry, mobility commanding information, 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 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 station
- Small science landers (CLPS)
- Robotic survey rover
- Radio telescope
- Surface communications station
- Long duration habitation station
- Lunar transfer vehicle
- Lunar surface power systems
- ISRU demonstration and pilot plants
- Crewed rover
- Solar physics telescope
- Medium-sized science landers
- Robotic exploration rover
- Landing beacon
- Communications tower

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 in essence forms the backbone of a Lunar Surface Network. 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 CSP or a link to Earth.

Recognizing the prevalence of commercially provided/owned landers and rovers, to avoid the potential interoperability problems among them due to the diversity of proprietary communication devices, it is determined that the Lunar Surface Network must be compliant with IEEE 802.11 standards, hence an instantiation of Lunar Wi-Fi.

The IEEE 802.11 standards offer a few advantages:

- Interoperability - They are industry standards for interoperability in wireless communications environment, specifically on the client equipment side.
- Cost efficiency – The abundance of commercially available communication devices using these standards gives the missions a more cost-effective solution.
- 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.

A limitation on Wi-Fi is that it is not interoperable on the infrastructure (access node) side: most vendors have their own proprietary method of communicating from one access point to another, such that in a heterogeneous environment all parties will have to agree on using the same vendor for their WIFI infrastructure to remain interoperable at a node-level (link various WLAN zones together). Other potential, viable alternatives are wireless network based on the Long Term Evolution (LTE) architecture, and 5G technology. Future infusion of the LTE architecture, and/or 5G technology and whether they replace the IEEE 802.11 or in addition to IEEE 802.11 and migration path, etc. is all future work and will be coordinated with the stakeholders.

There may be EVAs or HLS activates in the far side of the moon aka Shielded Zone of the moon. Given that the UHF frequency is detrimental to radio astronomy in this region, (Rec. ITU-R RA.479-5, Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon), the experiments/instruments will need to be placed into quiescent mode or turned off for the duration of the EVA and then turned back on again. The lander/rover to Earth communications will need to be relayed via an orbiting asset since there is no direct line of sight to Earth from the far side of the moon.

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 will 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 CSP communication links shall have a minimum 3 dB (**<TBR 3-5>**) 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.

Comm-231: All CCSP uncoded communication links shall have a frame error rate of less than or equal to 10^{-4} **<TBR 3-28>** 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 CSP coded communication links shall have a frame error rate less than or equal to 10^{-7} **<TBR 3-30>** 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 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.

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 will provide any additional the requirements needed for interoperability.

4.2 EXTENSION OF STANDARDS AND PROTOCOLS FOR DEEP SPACE MISSIONS

The ICSIS document addresses standards and protocols for CSP and other deep space vehicles. The current version of the document does not explicitly address standards and protocols for the deep space missions. 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 will 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.

In addition, the following interfaces will be considered for possible standardization:

- Direct communications with Earth for Crewed Vehicles in LLO
- Direct communications with Earth for crewed lunar bases as well as lunar surface communications between crewed rovers, habitat, landers, etc.

4.3 CONTINGENCY COMMUNICATIONS

The concept of operations to support spacecraft emergencies and contingencies is being worked at the CSP level and the supporting interoperability standards for contingency/emergency communications are currently being discussed and worked at the IOAG LCAWG and CSP. 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 CSP 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. That is the surest way to get an interoperable architecture up to and inducing 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 will be addressed in the next release of this Standard.

4.5 UPDATES FOR COMMUNICATIONS USING RELAY SATELLITES

The standards and protocols defined in this interoperability standard are agnostic and selected to work with direct as well as relayed communications for the most part. Future version of this document with will be updated to include any modifications needed to be compatible with a communications relay.

4.6 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. CSP plans to follow a process similar to ISS. Future version of this document will address commercial missions and payloads related spectrum management in further detail.

4.7 UNCREWED VEHICLES DOCKING WITH CSP

There may be additional communication needs or capabilities unique to uncrewed vehicles docking with the CSP on the CSP to VV communication link (example: logistics vehicles). 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.

4.8 NAVIGATION AND RADIOMETRIC TRACKING

This standard is set up to cover Position, Navigation, and Tracking (PNT) functions, but the initial focus is on the protocols and standards for communications. The navigation functions will be addressed in future revisions.

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
CSP	Cislunar Space Platform
CSTS	Cross Support Transfer Services
dB	Decibel
DES	Digital Encryption Standard
DG	Data Group
DOR	Differential One-Way Ranging
DSN	Deep Space Network
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
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
GHz	gigaHertz

GMAC	Galois Message Authentication Code
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
HD	High Definition
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
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
MAC	Medium Access Control
MCB	Multilateral Coordination Board
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
NEN	Near Earth Network
NIST	National Institute of Standards and Technology
NRZ-L	Non-Return-to-Zero-Level
NRZ-M	Non-Return-to-Zero-Mark
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 Tracking
PSK	Phase Shift Keying
Q	Quadrature
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RF	Radio Frequency
RFID	Radio Frequency Identification
RHCP	Right-Hand Circular Polarization
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
SSCS	Space-to-Space Communication Group
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

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

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.

CSP-GROUND

The term used for the Earth side of the interface that performs the required function. This could be ground station(s) (example: deep space network, near-earth network, etc.) or it could be a combination of ground station(s) and control center, 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 of more available ground stations.

LUNAR SYSTEM

An asset that is on the lunar surface, in the vicinity of the moon or in lunar orbit. These could be landers, rovers, other payloads, CubeSats, etc.

RELAY

Forward data from other CSP elements/payloads on to its destination, store data if link is not available

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	ECD
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.	CCSDS 355.1 ~ Dec.2020
3-2	3.2.2.4.2	Need to define signal characteristics for CSP-EVA communications	~ Dec. 2020
3-3	3.2.2.4.4	Need to determine security needs and requirements/standards for CSP-EVA communications	~ Dec. 2020
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	CCSDS 141.0 and 141.1 ~ Dec. 2020
3-6	3.2.2.5	RFID tag encoding standard needs to be added	~ Dec. 2020
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)	~Dec. 2020
3-8	3.2.2.2.3	Need to develop contingency communications standards	~Dec 2020
3-9	3.2.2.2.1.6.1, 3.2.2.2.2.1.5.1, 3.2.2.6.6.1	The value of what is considered as "low delay" needs to be determined.	~Dec 2020
3-10	3.2.2.2, 3.2.2.6	The CCSDS Document number needs to be assigned. This standard is in pre-draft stage and does not have a document number. References to this standard are no longer needed.	Closed June 2020

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	ECD
3-2	3.2.2.2.1.4	Need to agree on using CCSDS 506.1-B-1, Delta-DOR Raw Data Exchange format. Requirement deleted	Closed June 2020
3-3	3.2.2.4.1	The frequency for the CSP-EVA (proximity communications) – being proposed as UHF needs to be resolved -- closed	Closed June 2020
3-4	3.2.2.4.3	ISS SSCS frame and network control architecture is proposed for the CSP-EVA communication system – this needs to be resolved within the standards team -- closed	Closed June 2020
3-5	3.3	Need to finalize how much link margin should be carried for CSP communication links	~ Dec. 2020
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.	~ Dec. 2020
3-12	3.2.2.5	Need to resolve if we want to have IEEE 802.11.ac and if so, what standard to use	~Jun 2021
3-13	3.2.2.5,	Need to resolve if we want to have LTE and if so, what standard to use	~Jun 2021
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.	~ Jun 2021
3-15	3.2.2.2.2.1.2, 3.2.2.2.2.1.3, 3.2.2.2.2.1.4, 3.2.2.2.2.1.5.1, 3.2.2.2.2.1.6,	Ka-band uplink side of interface has not yet been implemented and a minimum implementation is provided here for guidance. TBR will be removed when we get agreement on the Ka-band uplink implementation by the partners.	~ April 2021
3-16	3.2.2.2.1.6.1, 3.2.2.2.2.1.5.1, 3.2.2.6.6.1	Need to resolve between IPv4 and IPv6; Gateway has baselined IPv4 after looking at both IPv4 and IPv6 – availability of space hardware, vendor support, etc.	~ Dec. 2020
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	~ Dec. 2020
3-18	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 to implement streamlined bundle security protocol once standards has been baselined and agreed to implementation by the partners. *DTN community has abandoned work on this standard and will be working on incorporating the bundle security as part of BPv7. Removed callout to streamlined bundle security protocol.*	Closed June 2020
3-19	3.2.2.2.1.6.3, 3.2.2.2.2.1.5.3,	Option to use IPSec when not using secure DTN bundling	~Dec. 2020

TBR	Section	Description	ECD
	3.2.2.3.6, 3.2.2.6.6.3		
3-20	3.2.2.3.6, Appendix H	implementation of bundle protocol, by visiting vehicles – No requirement for CSP-VV link to implement DTN	Closed June 2020
3-21	3.2.2.3.6	implementation of LTP by visiting vehicles No requirement for CSP-VV link to implement LTP	Closed June 2020
3-28	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	Cases for using LTP over UDP need to be understood and finalized.	~Dec 2020
3-29	3.3	Need to finalize performance metric on uncoded links.	~ Dec 2020
3-30	3.3	Need to finalize performance metric on coded links.	~ Dec 2020

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)

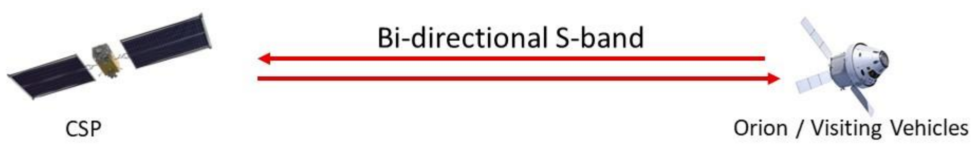
1. Commands
2. Configuration initialization and updates
3. GNC State information
4. Software updates
5. Data uploads (procedures, files, images, etc.)
6. Relayed Commands, etc. to other modules
7. Support Radio Frequency ranging (Radiometric tracking)

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 CSP 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

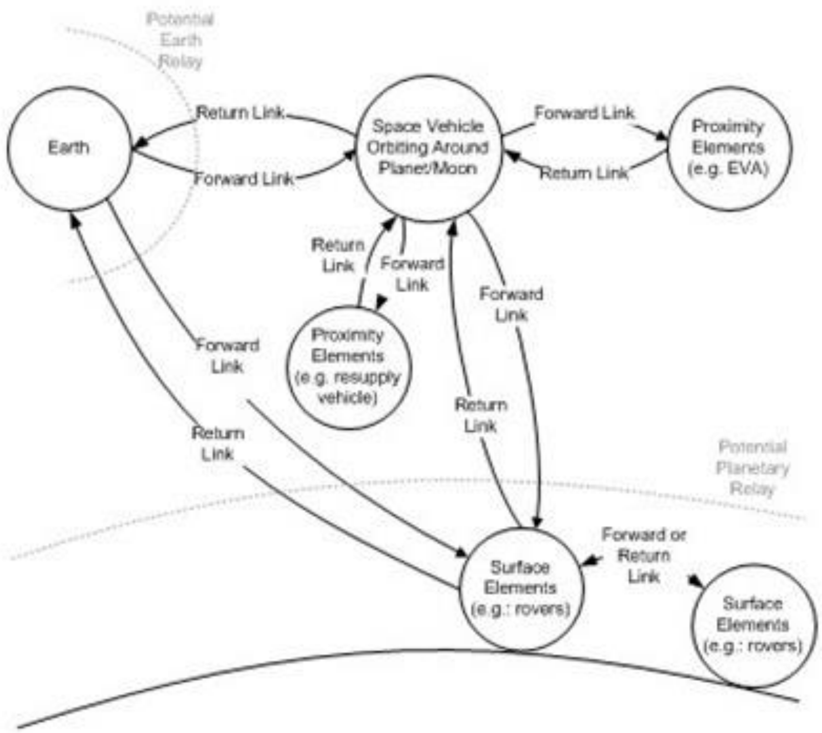
Orion/VV to CSP ---- during Rendezvous and Docking/berthing

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 DATA TRANSFER BETWEEN CSP AND VISITING VEHICLE (EXAMPLE: ORION)

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. Definition of interoperability standards for these links are currently not within the scope of this document.

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))

<table>
<tr><th><u>Communication Link</u></th><th><u>Forward Link</u></th><th><u>Return Link</u></th><th><u>Data Rate Justification</u></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>

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, range rate 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.).

APPENDIX G – CCSDS STANDARDS DEVELOPMENT SCHEDULE

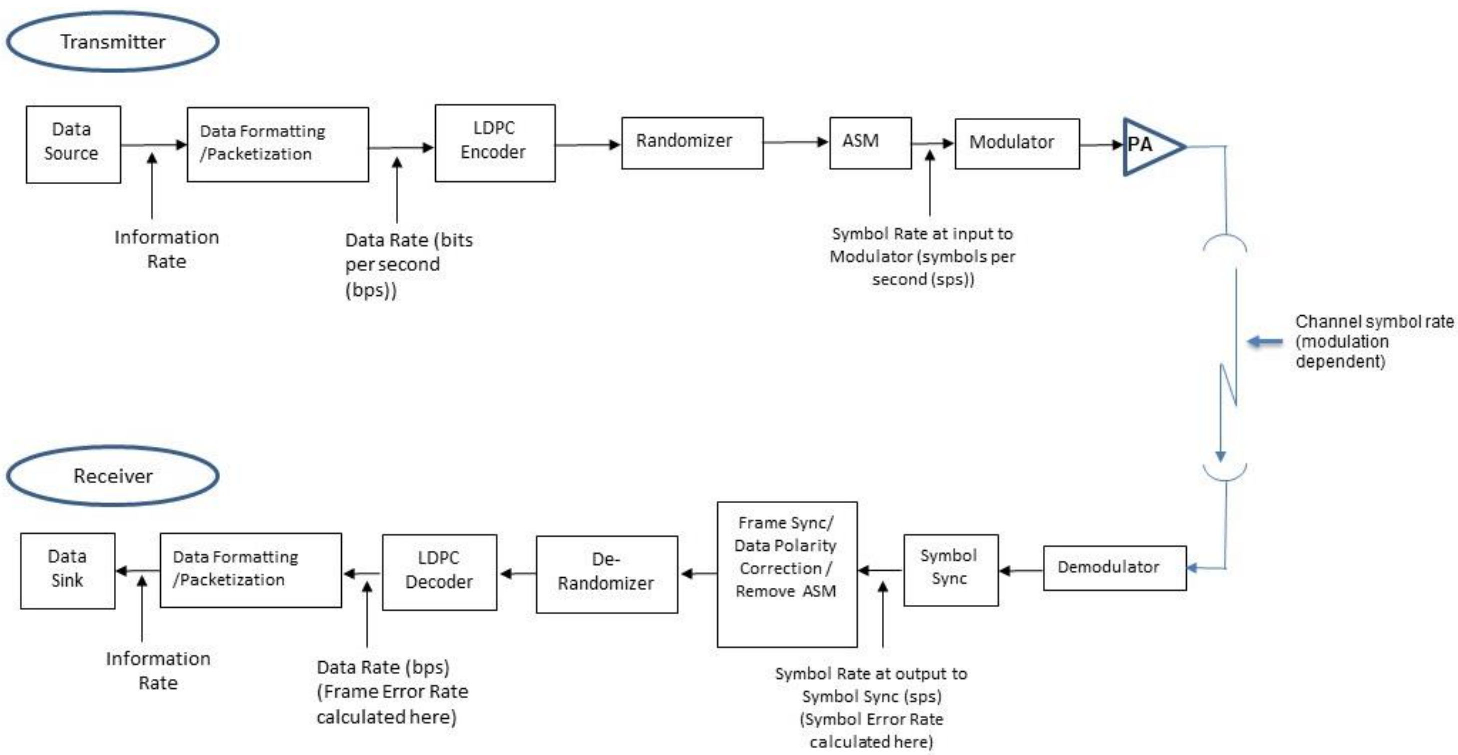
TITLE	BOOK	STATUS	YEAR COMPLETED (LAST REVISION)	CCSDS ESTIMATE FOR COMPLETION / REVISION	DOC TYPE (END STATE)
TM Synchronization and Channel Coding	131.0	COMPLETE	2017	-	Blue
Encapsulation Service	133.1	COMPLETE	2012	-	Blue
Optical Communications Physical Layer	141.0	COMPLETE	2019	-	Blue
Optical High Data Rate Communications (1550)	141.10	WORKING DRAFT	-	2020	Orange
Proximity-1 Space Link Protocol-Data Link Layer	211.0	COMPLETE	2013	-	Blue
Proximity-1 Space Link Protocol--Physical Layer	211.1	COMPLETE	2013	-	Blue
Proximity-1 Space Link Protocol--Coding and Synchronization Sublayer	211.2	COMPLETE	2013	-	Blue
Time Code Formats	301.0	COMPLETE	2010	-	Blue
CCSDS Global Spacecraft Identification Field Code Assignment Control Procedures	320.0	COMPLETE	2017	-	Magenta
CCSDS Cryptographic Algorithms	352.0	COMPLETE	2013	-	Blue
Space Data Link Security (SDLS) protocol	355.0	COMPLETE	2015	-	Blue
SDLS Extended Procedures	355.1	COMPLETE	2020	-	Blue
Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft.	401.0	COMPLETE	2020	-	Blue
Pseudo-Noise (PN) Ranging Systems	414.1	COMPLETE	2015	-	Blue
Tracking Data Message	503.0	COMPLETE	2007	2020	Blue
Delta-Differential One Way Ranging (Delta-DOR) Operations	506.0	COMPLETE	2017	-	Magenta
Delta-DOR Raw Data Exchange Format	506.1	COMPLETE	2013	2020	Blue
IP over CCSDS Space Links	702.1	COMPLETE	2012	-	Blue
CCSDS File Delivery Protocol (CFDP)	727.0	COMPLETE	2007	2020	Blue
AOS Space Data Link Protocol	732.0	COMPLETE	2015	-	Blue
Unified Space Data Link Protocol	732.1	COMPLETE	2018	-	Blue
Licklider Transmission Protocol (LTP) for CCSDS	734.1	COMPLETE	2014	-	Blue
Bundle Protocol Specification	734.2	COMPLETE	2015	-	Blue
~~Bundle Security Protocol for CCSDS~~	~~734.5~~	~~WORKING DRAFT~~	~~-~~	~~2021 (TBC)~~	~~Blue~~
Asynchronous Message Service (AMS)	735.1	COMPLETE	2011	-	Blue
Digital Motion Imagery	766.1	COMPLETE	2015	-	Blue
Voice and Audio Communications	766.2	COMPLETE	2017	-	Blue
XML Specification For Electronic Data Sheets	876.0	COMPLETE	2019	-	Blue
Spacecraft Onboard Interface Services—RFID-Based Inventory Management Systems, Recommended Practice	881.0	COMPLETE	2012	-	Magenta
CCSDS Wireless Proximity Network Standard	883.0	WORKING DRAFT Orange		2021	Blue
Space Communications Cross Support--Architecture Requirements Document	901.1	COMPLETE	2014	-	Magenta
Space Link Extension--Return All Frames Service Specification	911.1	COMPLETE	2017	-	Blue
Space Link Extension--Return Channel Frames Service Specification	911.2	COMPLETE	2017	-	Blue
Space Link Extension-- Space Link Extension--Forward CLTU Service Specification	912.1	COMPLETE	2017	-	Blue
Cross Support Transfer Services—Specification Framework	921.1	COMPLETE	2017	-	Blue
Monitored Data - Cross Support Transfer Services	922.1	COMPLETE	2017	-	Blue
Coding & Synchronization Sub-layer High Rate Uplink Protocol for AOS & USLP.	UNK	PLANNED (PRE-DRAFT)	-	2021	Blue

APPENDIX H – REFERENCE LINK MARGINS

The margins provided in this Appendix is **<u>for reference purposes only</u>**. 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.

CSP 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 AS	**-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)	

Earth to CSP Link (NEN 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 NEN Axial Ratio: TBD	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)	

CSP 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)	

Visiting Vehicle Link to CSP – 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)