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HUMAN LANDING SYSTEM (HLS) SUSTAINING PHASE RADIO FREQUENCY (RF) COMMUNICATIONS CONCEPT OF OPERATIONS

REVISION AND HISTORY PAGE

Revision No.	Change No.	Description	Release Date
-	HLS-C0216	Initial Release (Reference HCB.01.12.2022)	02/03/2022
-	HLS-MD-0006	Updated HLS-IRD-004 to reflect HLS-IRD-004-01 Sustaining Volume numbering.	02/22/2022
A	-	Revision A (Reference OSB HCB.06.28.2022) The terminology updates add the “Integrated Lander” wording consistent with the other HLS SLD documents. The definitions/glossary updates add definitions for the words used in the HLS-CONOP-008 from the SOW, HLS-CONOP-006, or HLS-RQMT-006 in that order as appropriate. Added wording to the description of the HLS direct with Earth frequency band options to include S-band in section 4.3 HLS Frequency Selection and Spectrum Planning, bullet 1. Direct-with-Earth bi-directional Communications.	07/07/2022
A	Administrative Change 1	Administrative change to correct Data Marking label and footers per HLS PMO and Export Control Representative	3/21/2025

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1.0 INTRODUCTION

The Sustaining Phase Human Landing System (HLS) Radio Frequency (RF) Communications Concept of Operations (ConOps) describes the general communications systems concepts that will enable a sustained human lunar presence. The HLS Integrated Lander is a vehicular system that first transports lunar surface exploration logistics and mission support equipment from Earth to near-rectilinear halo orbit (NRHO), then transports crew members from a Crew Staging Vehicle (CSV) in a NRHO to the lunar surface, enables the crew to perform multiple extravehicular activities (EVAs) and access surface assets, and then safely returns the crew to the CSV for return to Earth (RTE). In addition to returning the crew to NRHO, the HLS Integrated Lander also returns lunar samples and other equipment to NRHO to enable sample RTE for scientific study.

While the HLS Integrated Lander will have the capability to communicate concurrently with ground support teams on Earth (Mission Systems), the Crew Staging Vehicle (Gateway) in a NRHO, EVA Spacesuits, and Lunar Surface Assets, when present, the specific communication needs will vary by Artemis mission segment (e.g., Ascent, RPOD, Docked Operations), and by the availability of communications assets. During all crewed mission phases, continuous communications between Earth, Gateway, Spacesuits, and Lunar Surface Assets is required. Therefore, the HLS Provider(s) must provide sufficient Ground Station and/or Relay satellite coverage such that no unplanned communications outages occur during crewed HLS operations.

1.1 PURPOSE

The primary purpose of this document is to define the RF communications concept of operations for the sustaining phase Human Landing System portion of the NASA Artemis effort to establish a sustained human presence on the Moon. This document captures the top level RF communications systems concepts for how the HLS sustaining phase Provider(s) will be expected to specify and use the HLS RF Communications and Tracking Systems in the broader NASA effort.

The HLS sustaining phase Design Reference Missions (DRMs) are included to describe the current understanding of the bounding mission types to be used in the sustaining phase of lunar exploration. The DRMs establish an operational context, descriptions of situations that will be encountered during currently available mission concepts, and top-level operational sequences with a focus on sequences involving interaction between HLS Integrated Lander and non-HLS Integrated Lander communications systems and NASA crew. The DRMs are also intended to capture communication capabilities, rather than a manifest or specific mission plan.

The three-element HLS Integrated Lander design concept provided herein is the NASA Government Reference Concept and is one of many possibilities. This design concept is provided solely as a reference and is not intended to represent any of the HLS Provider(s) design solutions.

1.2 SCOPE

This document defines the general RF communications concepts for the sustaining phase of the return to the Moon and is based on the Government reference design. While usage of RF communications is the focus of this ConOps, HLS Provider(s) are not precluded from proposing optical communications for links that are not interface-limited to RF communications.

NASA has divided the Artemis campaign into two phases—an initial phase and a sustaining phase. This document covers the early portions of the Sustaining Phase missions that are covered by the HLS sustaining period of performance. This document is limited to the timeframe during which the HLS Integrated Lander interacts with the Orion, Gateway, NASA crew, Exploration Extra-Vehicular Activities (xEVA) system, NASA Mission Systems, Lunar Relay System, and/or pre-positioned lunar assets (sustaining habitations, pressurized rovers, and/or Lunar Terrain Vehicles). The DRMs/architecture concepts presented within this document are for reference purposes only and are not intended to represent any of the HLS Provider(s) design solutions. The specific RF communication systems architecture/ implementation of this RF Communications ConOps will be housed in future documentation.

1.3 CHANGE AUTHORITY/RESPONSIBILITY

Proposed changes to this document shall be submitted via a Change Request (CR) to the appropriate Human Landing System Control Board for consideration and disposition.

All such requests will adhere to the Human Landing System Configuration and Data Management Plan, documented in HLS-PLAN-004. The appropriate NASA Office of Primary Responsibility (OPR) identified for this document is HLS Systems Engineering & Integration Office.

1.4 APPLICABLE DOCUMENTS

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

Table 1-1 Applicable Documents

Document Number	Document Title
HLS-CONOP-006	Sustained Phase HLS Program Concept of Operations
HLS-PLAN-004	HLS Configuration and Data Management Plan
HLS-IRD-004-01	Human Landing System (HLS) Program Integrated Lander to Mission Systems (MS) Interface Requirements Document (IRD) - Sustained Phase
HLS-IRD-008	Human Landing System (HLS) Program Integrated Lander to Lunar Surface Assets (LSA) Interface Requirements Document (IRD) – Sustained Phase
GP-10031-01	Gateway to HLS Visiting Vehicle Interface Requirements Document
GP 10045-01	Gateway to Visiting Vehicle RF IRD - HLS Annex
GP 10046-01	Gateway to Lunar Systems RF IRD, HLS Annex
EVA-EXP-0067	xEVA Interface Requirements Control Document
HLS-RQMT-006	Human Landing System (HLS) Program Integrated Lander Requirements Document – Sustained Phase

Table 1-1 Applicable Documents

Document Number	Document Title
HEOMD-007	HEOMD SCOPE
HEOMD-003-02	International Communications System Interoperability Standards
NASA-STD-1006	Space System Protection Standard
NPR 2810.1	Security of Information Technology

1.5 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document.

Table 1-2 Reference Documents

Document Number	Document Title
AES-50007	AES Concept of Operations
GP-10027	Gateway Concept of Operations
EVA-EXP-0042	EVA OFFICE EXPLORATION EVA SYSTEM CONCEPT OF OPERATIONS
HLS-PLAN-016	HLS Technical Management Plan
SPD-1	Space Policy Directive-1 Reinvigorating America's Human Space Exploration Program
SPD-5	Space Policy Directive - 5
SFCG 32-2R3	Communication and Positioning, Navigation, and Timing Frequency Allocations and Sharing in the Lunar Region (December 2021)

2.0 SUMMARY

The Human Landing System Integrated Lander is a vehicular system that enables the transport of logistics and mission support equipment from Earth to an Earth-Moon L^2 NRHO oriented over the southern pole with a 9:2 synodic resonance with the Moon's orbit. The HLS Integrated Lander then transports crew members and cargo from the CSV in a NRHO to the lunar surface, provides crew habitation and EVA support on the surface, and then safely returns crew and cargo to the CSV for return to Earth. The HLS Sustaining Phase missions will require the HLS Integrated Lander to dock to Gateway, land a complement of up to four crew on the lunar surface for either a sortie mission or excursion with transfer to pre-emplace habitable lunar assets, operate for extended durations near the lunar south pole, and support eight-hour EVAs to help further the advancement of surface goals. The sustaining phase missions are characterized by two primary

DRMs, and a non-polar DRM variant, which are described in greater detail in the following DRM section.

This document defines the general RF communication capabilities and concepts needed to support the HLS Sustaining Phase Design Reference Missions defined in the HLS-CONOP-006, Sustained Phase HLS Program ConOps.

2.1 HLS PROGRAM PHASES

The Artemis campaign is divided into two major phases - an initial and a sustaining. While the scope of this document is the sustaining phase missions, a description of the initial phase is provided for context and background. Summaries of both phases are included below.

HLS Initial Phase Mission Summary:

- Lunar South Pole Mission(s) (within 6˚ of pole)
- No pre-emplaced Assets Required
- Two (2) crew members inside HLS Integrated Lander
- Option to use Orion or Gateway as the Crew Staging Vehicle.
- 6.5-Earth-day Surface-Stay duration

HLS Sustaining Phase Mission Summary:

- Lunar South Pole Missions; however, goal capability for sortie missions to non-polar locations
- Lunar surface assets, including Sustaining Habitations, Pressurized Rover, & Lunar Terrain Vehicles
- Up to four (4) crew members inside HLS Integrated Lander
- Use of Gateway as the Crew Staging Vehicle (CSV) for primary DRMs and DRM variants.
- Longer Surface-Stay Durations

Note: The sustaining mission phase does not require that HLS Integrated Lander elements be re-used; however, the sustaining mission phase may have re-usable elements. Some DRMs of the sustaining mission phase will rely on pre-emplaced assets to carry out lunar missions.

3.0 DESIGN REFERENCE MISSIONS

The DRMs in this section are intended to serve as the bounding mission cases that drive HLS Integrated Lander system and mission design and are to be used in the sustaining phase period of performance of the Artemis lunar exploration campaign. DRM variants are intended to serve as representation of how the capability established by the primary DRM may be used in different operational contexts and external environments than would be seen during a mission represented by the primary DRM. The sustaining phase DRMs are described in greater detail within HLS-

CONOP-006. Table 3-1 provides an overview of the sustaining phase DRMs with Gateway as the Crew Staging Vehicle (CSV).

Table 3-1 Design Reference Mission Overview

	Primary DRMs		**DRM Variant**
	DRM-001 Polar Sortie	**DRM-002 Polar Extended Excursion**	**DRM-001b Non-Polar Sortie**
Crew Staging Vehicle	Gateway	Gateway	Gateway
Landed Crew Size	2	4	2
Surface Stay (days)	6	33	2(threshold) – 6 (goal)
Landing Location	South Pole	Artemis Base Camp	Non-Polar
Darkness (hr)	0-40	120-192	0-40
Surface Habitation	HLS Integrated Lander	HLS and Artemis Base Camp Elements	HLS Integrated Lander
Number of HLS EVAs	5 (4 planned, 1 unplanned)	2 (1 full round- trip transfer by EVA, 1 unplanned)	2 (threshold) 5 (goal)

Figure 3-1 shows a notional Sustaining Phase mission with three different architecture types.

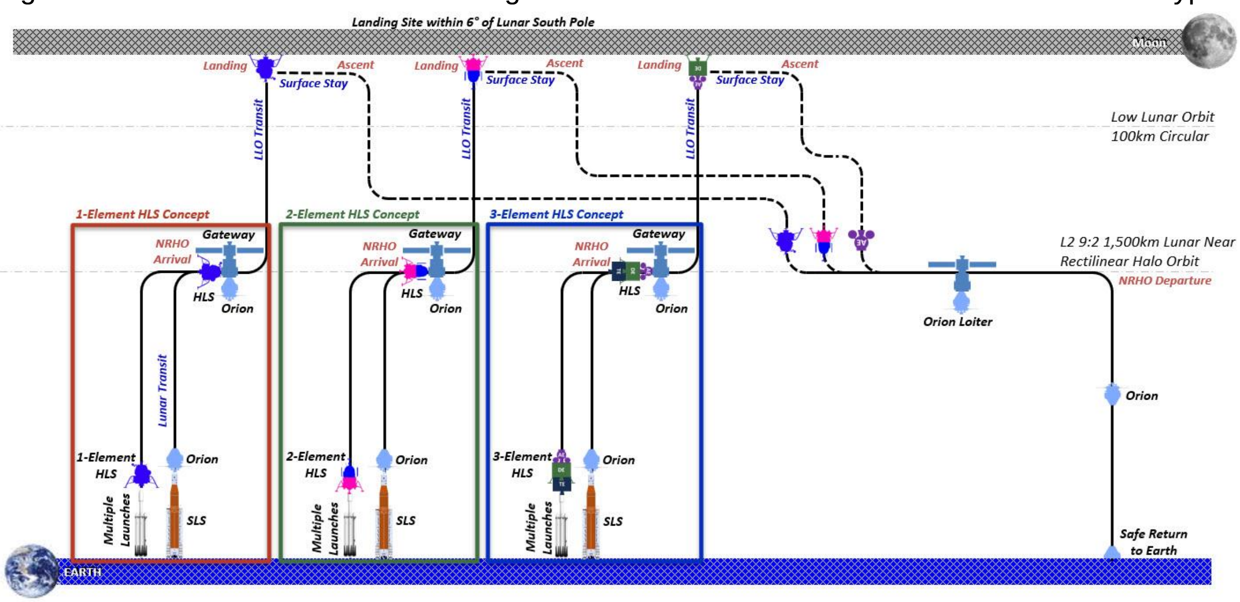


Figure 3-1 (Notional) Sustaining Phase Mission Architectures

For this RF ConOps, a three-element (i.e. Transfer Element (TE), Descent Element (DE), and Ascent Element (AE)) NASA reference architecture is assumed, as shown in Figure 3-2, and this architecture is one of many possible HLS Integrated Lander design solutions and is not intended to drive implementation.

For each DRM, a NRHO lunar staging orbit (LSO) is assumed for the lunar surface mission. In order to protect for the inability of the HLS Integrated Lander to dock with the Gateway upon return and transfer the crew to Orion through Gateway, the HLS Integrated Lander must have the ability to dock to Orion in a contingency case, which requires a docking mechanism compatible with Orion's active docking mechanism. The HLS Integrated Lander may require an Active-Active Docking Adapter (AADA) or an androgynous docking adapter for docking to Gateway. This docking adapter may be disposed of at end of mission if a subsequent HLS mission does not require its use (NASA decision).

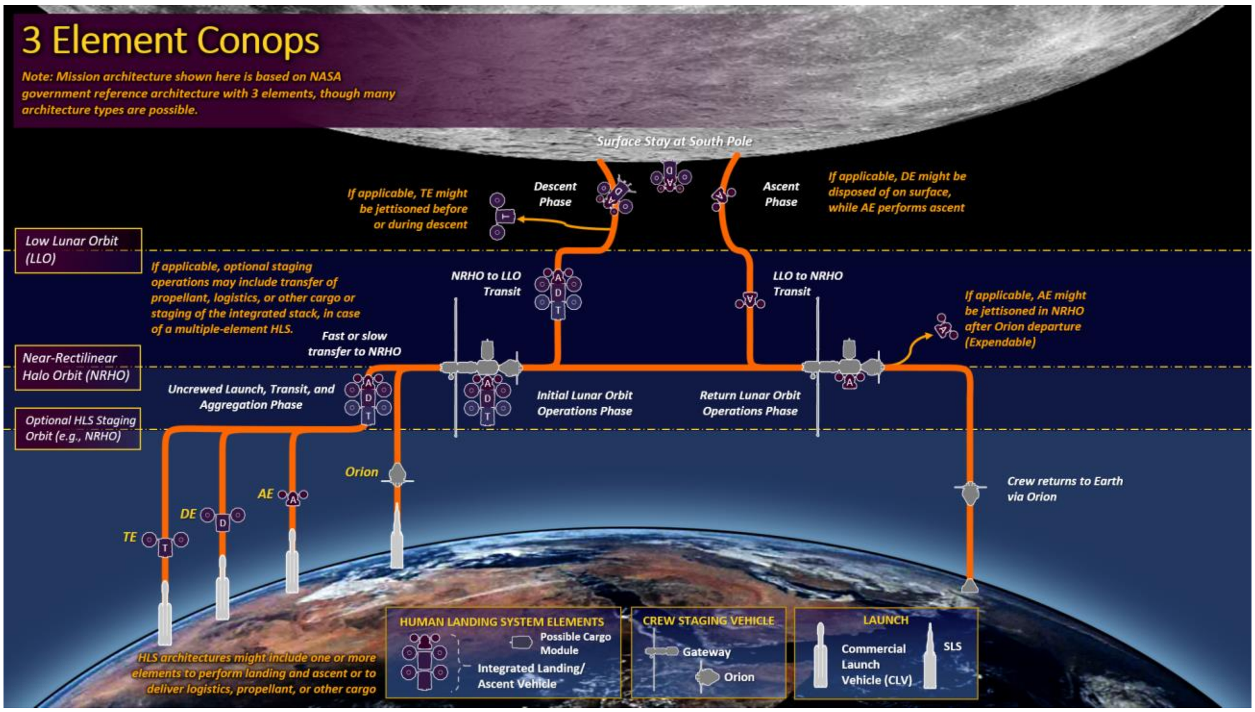


Figure 3-2 Generic sustained phase mission architecture. The three-element architecture is for reference only and represents one possible approach

For DRM-001, DRM-001b, and DRM-002, the Gateway is utilized as the Crew Staging Vehicle; therefore, HLS Integrated Lander needs the following capabilities:

1. The capability to communicate Direct-with-Earth (DWE) and Relayed-with-Earth (Lunar Relay).
    a. Note 1: HLS Integrated Lander may rely upon NASA communication relays or relays delivered by non-NASA entities, including commercial providers.
    b. Note 2: The capability to communicate with the NASA SCaN-provided orbital relay or a commercial Relay will allow all Mission Objectives to be met when operating from a non-DWE landing site, and augment comm when operating from a DWE

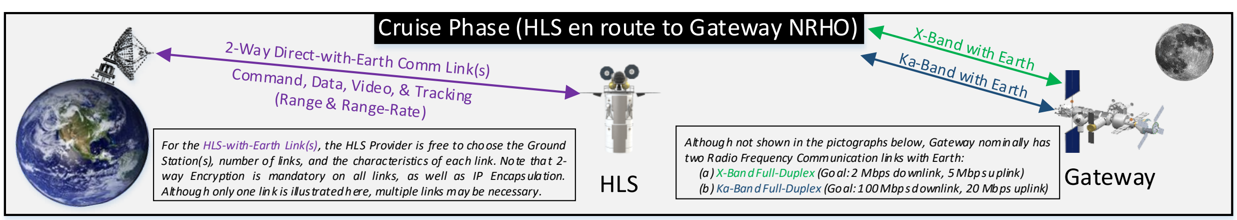
landing site.

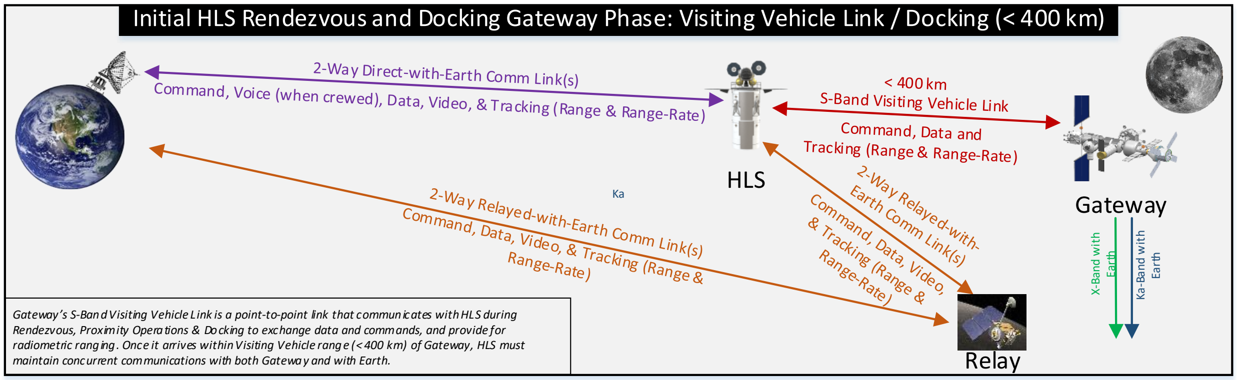
2. The capability to communicate directly with Gateway (Gateway Visiting Vehicle Link) when within 400 km.
3. The capability to exchange crew, payload, power, data, commands, and atmosphere with Gateway when attached.
4. The capability to communicate with Gateway when outside of 400 km via Gateway Lunar Systems Link(s) (provides non-DWE link to Earth as well as provides required HLS crew to Gateway crew communications).
    a. Note that designing for compatibility with the Gateway lunar link(s) is expected to also provide compatibility with the NASA-provided Lunar Orbiting Communication Relay(s). Of course, this does not preclude the use of commercially-provided communications relay assets in addition to the Gateway and NASA relay.
5. The capability to communicate with surface assets (i.e., EVA Suits, Lunar Terrain Vehicle (LTV), Pressurized Rover (PR)) either directly or indirectly (utilizing surface repeaters/relays).
6. The capability to communicate directly with Orion when within 800 km (applicable for the contingency docking scenario).
7. The capability to communicate with Orion when outside of 800 km via an indirect communication path such as DWE, Relayed-with-Earth (RWE), and/or Gateway (applicable for the contingency docking scenario).

4.0 COMMUNICATIONS SYSTEMS OVERVIEW

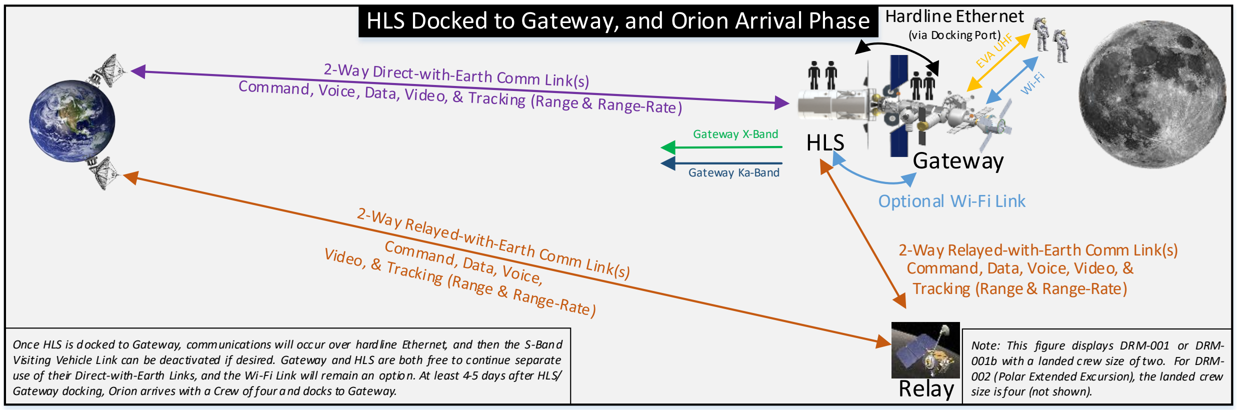
4.1 COMMUNICATIONS ARCHITECTURE OVERVIEW

The diagrams in Figure 4-1 below display an overview of the communication architecture for the sustaining phase DRMs.

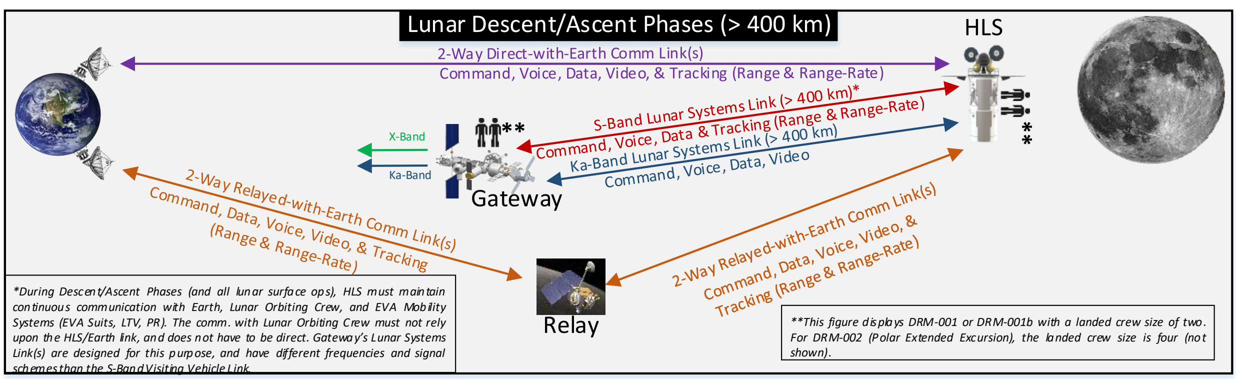




Initial HLS Rendezvous and Docking Gateway Phase: Visiting Vehicle Link / Docking (< 400 km)
2-Way Direct-with-Earth Comm Link(s)
Command, Voice (when crewed), Data, Video, & Tracking (Range & Range-Rate)
HLS
< 400 km
S-Band Visiting Vehicle Link
Command, Data and Tracking (Range & Range-Rate)
Gateway
Ka
2-Way Relayed-with-Earth Comm Link(s)
Command, Data, Video, & Tracking (Range & Range-Rate)
2-Way Relayed-with-Earth Comm Link(s)
Command, Data, Video, & Tracking (Range & Range-Rate)
X-Band with Earth
Ka-Band with Earth
Relay
Gateway's S-Band Visiting Vehicle Link is a point-to-point link that communicates with HLS during Rendezvous, Proximity Operations & Docking to exchange data and commands, and provide for radiometric ranging. Once it arrives within Visiting Vehicle range (< 400 km) of Gateway, HLS must maintain concurrent communications with both Gateway and with Earth.



HLS Docked to Gateway, and Orion Arrival Phase
Hardline Ethernet
(via Docking Port)
EVA UHF
Wi-Fi
2-Way Direct-with-Earth Comm Link(s)
Command, Voice, Data, Video, & Tracking (Range & Range-Rate)
Gateway X-Band
Gateway Ka-Band
HLS
Gateway
Optional Wi-Fi Link
2-Way Relayed-with-Earth Comm Link(s)
Command, Data, Voice, Video, & Tracking (Range & Range-Rate)
2-Way Relayed-with-Earth Comm Link(s)
Command, Data, Voice, Video, & Tracking (Range & Range-Rate)
Relay
Once HLS is docked to Gateway, communications will occur over hardline Ethernet, and then the S-Band Visiting Vehicle Link can be deactivated if desired. Gateway and HLS are both free to continue separate use of their Direct-with-Earth Links, and the Wi-Fi Link will remain an option. At least 4-5 days after HLS/Gateway docking, Orion arrives with a Crew of four and docks to Gateway.
Note: This figure displays DRM-001 or DRM-001b with a landed crew size of two. For DRM-002 (Polar Extended Excursion), the landed crew size is four (not shown).



Lunar Descent/Ascent Phases (> 400 km)
HLS
2-Way Direct-with-Earth Comm Link(s)
Command, Voice, Data, Video, & Tracking (Range & Range-Rate)
S-Band Lunar Systems Link (> 400 km)*
Command, Voice, Data & Tracking (Range & Range-Rate)
Ka-Band Lunar Systems Link (> 400 km)
Command, Voice, Data, Video
X-Band
Ka-Band
Gateway
2-Way Relayed-with-Earth Comm Link(s)
Command, Data, Voice, Video, & Tracking (Range & Range-Rate)
Relay
2-Way Relayed-with-Earth Comm Link(s)
Command, Data, Voice, Video, & Tracking (Range & Range-Rate)
*During Descent/Ascent Phases (and all lunar surface ops), HLS must maintain continuous communication with Earth, Lunar Orbiting Crew, and EVA Mobility Systems (EVA Suits, LTV, PR). The comm. with Lunar Orbiting Crew must not rely upon the HLS/Earth link, and does not have to be direct. Gateway's Lunar Systems Link(s) are designed for this purpose, and have different frequencies and signal schemes than the S-Band Visiting Vehicle Link.
**This figure displays DRM-001 or DRM-001b with a landed crew size of two. For DRM-002 (Polar Extended Excursion), the landed crew size is four (not shown).

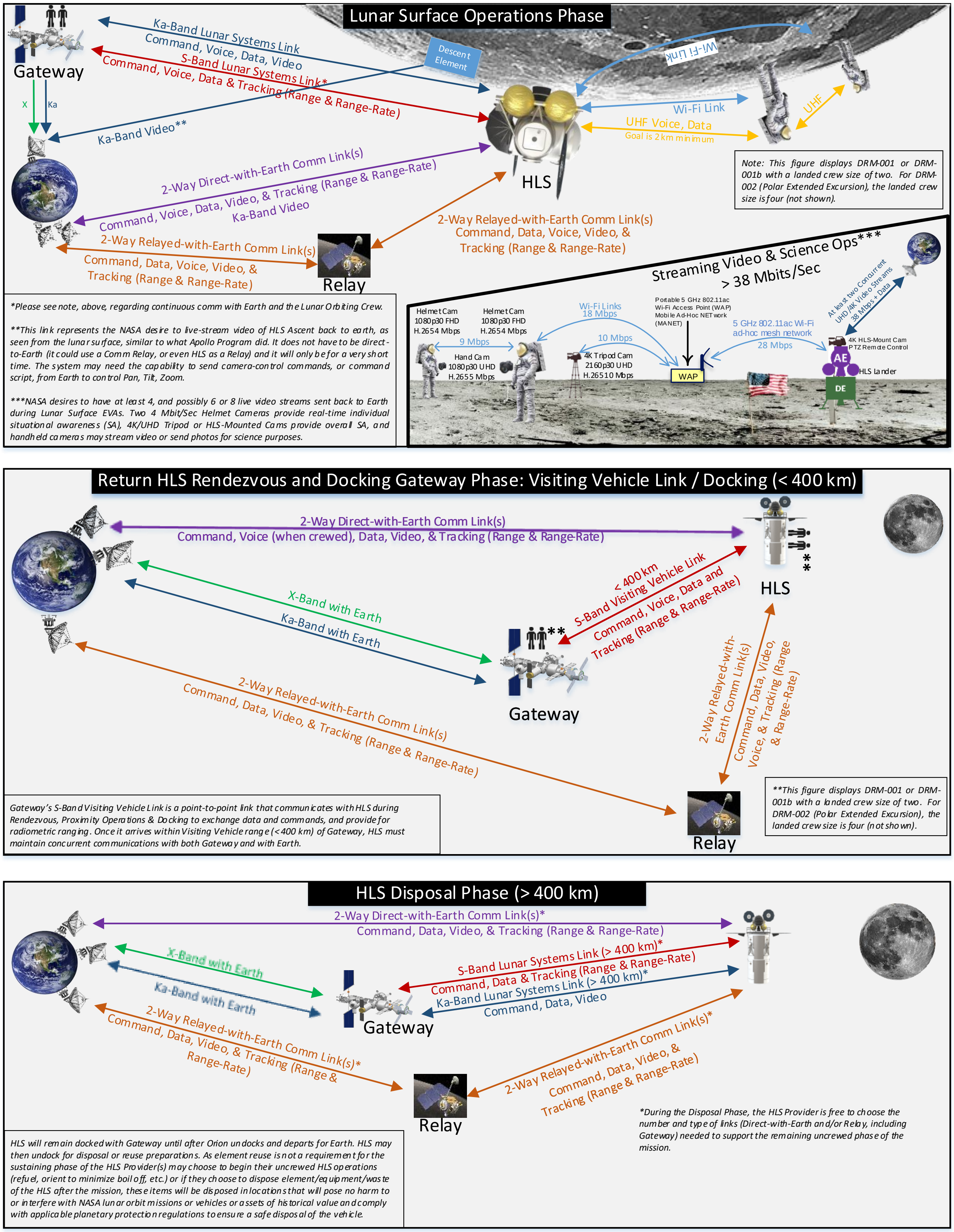


Figure 4-1 Communication Architecture Overview for the Sustaining Phase DRMs

4.2 COMMUNICATIONS PRIORITY SCHEME

In all HLS RF Communications Systems, the two-way priority scheme is defined as follows:

- Highest priority will be given to given to Crew Voice Communications.
- Second Highest-Priority will be Emergency, Caution & Warning (Alert) Notifications and EVA suit health and status telemetry data.
- Third Highest-Priority will be given to command data, HLS health and status telemetry data, video, and file transfers.

At a minimum, the Communications System(s) need the ability to communicate by voice conversation (10 kilobits/sec per voice channel). Alert notifications will be added if the data rates allow, and these may be prioritized based on their severity.

The current HLS ConOps is to have the capability to maintain dissimilar communication paths with Earth, Direct-with-Earth and/or Relayed-with-Earth links, and concurrently with Gateway, during all mission phases for command uplink, ranging, data, voice (when crewed), video, and status to mitigate unforeseen communications outages. For planned outages, where either the DWE and/or RWE links are not available, the Gateway can also be used as a relay with Earth. During all crewed mission phases, continuous communications is required; thus, the HLS Provider(s) must provide sufficient ground station and/or relay satellite coverage such that no unplanned communications outages occur during crewed HLS operations. With the HLS Integrated Lander on the lunar surface, the range to Gateway (in NRHO) could be up to 70,000 km and, during descent and ascent, it can be expected to have roughly a maximum of 22,000 km distance to Gateway (in NRHO) for normal operations. Therefore, the Gateway Lunar Systems Links are designed to communicate at distances up to 70,000 km and should thus successfully close at all expected distances.

For HLS Integrated Lander/Gateway crosslink communications (at all anticipated lunar distances), higher-rate communication is possible, and the actual communication link(s) implementations details would be up to the HLS Provider(s). During surface EVA activities, the HLS Integrated Lander uses a UHF EVA Link to support astronaut voice and biomedical data links and uses an external Wi-Fi link to support high-rate communications for peripheral devices (such as Video Cameras or Science Instruments) for EVA activity.

For the contingency docking with Orion case, HLS Integrated Lander will maintain continuous communications with Orion when within 800 km (Proximity Operations) as well as a continuous Direct-with-Earth and/or Relayed-with-Earth link (*Note: Gateway could also be used as a relay with Earth.*).

4.2.1 Autonomous Operation and Communication Outages

Per HLS-CONOP-006, any uncrewed HLS Integrated Lander element operating in the lunar vicinity will do so using ground-based command and control (direct or via relay asset) and/or a combination of automation and/or autonomy. Therefore, the design of operational scenarios must consider communications latency and communications coverage when Mission Control is in the operational command and control and/or decision loop. However, this does not imply any requirements on ground-based control versus autonomous operations.

For periods where continuous communication is not required, such as uncrewed quiescent operations (e.g. loiter within NRHO, etc.), the HLS Integrated Lander may have the opportunity of operating more autonomously during pre-planned communication coverage outages. In addition, communications coverage can also be lost for any number of reasons; therefore, it is recommended that HLS Integrated Lander should have the autonomous capability to operate for at least 12-24 hours (typically recommended) of unplanned loss of communications.

4.3 HLS FREQUENCY SELECTION AND SPECTRUM PLANNING

The HLS Integrated Lander will need to make provisions for Radio Frequency Communications utilizing the frequency bands that are allocated in the US domestic regulations and in the International Telecommunication Union (ITU) Table of Frequency allocation as specified below:

1. Direct-with-Earth bi-directional Communications:
    a. X-Band is limited to spacecraft tracking, telemetry and command (TT&C) operations.
    b. Ka-Band can accommodate wider bandwidths, such as 2-way telerobotic operation, science data return and, video streams while including spacecraft TT&C.
    c. S-Band, while still permitted for DWE communications, is subject to spectrum crowding and licensing restrictions. Permanent licenses for near-earth S-Band use will no longer be granted by ITU, and temporary licenses are unreliable for full HLS Mission coverage.
    d. All frequency requests are subject to NASA Lunar Spectrum Manager review and completion of an interagency technical pre-coordination process prior to regulatory approval.
    e. Transmit authority of the pre-coordinated spectrum uses will be subject to licensing approval through the Federal Communications Commission (FCC) and compliant with ITU filing results.
2. Orion Proximity or Gateway Visiting Vehicle Communications will be via bi-directional S-Band Link and are generally intended for direct communication between vehicles for rendezvous, proximity operations, docking and undocking (RPODU) purposes:
    a. Orion: Distances up to 800 km, with radiometric ranging and data transfers.
        i. Orion can support radiometric ranging out to a maximum distance of 800km. However, low-rate communication links with Orion, without ranging, are possible far beyond 800 km, subject only to link margin limitations.
    b. Gateway: Distances up to 400 km, with radiometric ranging and data transfers.

i. For distances beyond 400km, use the Gateway Lunar Systems Link(s) as described below.

c. All frequency requests are subject to NASA Lunar Spectrum Manager review and completion of an interagency technical pre-coordination process prior to regulatory approval.

d. Transmit authority of the pre-coordinated spectrum uses will be subject to licensing approval through the Federal Communications Commission (FCC) and compliant with ITU filing results.

3. Gateway Lunar Systems Link(s) for separation distances > 400km, including from the surface of the Moon:

    a. Distances up to 70,000 km from Lunar South Pole to NRHO perilune.

    b. Gateway Lunar Systems link(s)s are S-Band and Ka-Band, which may both be used concurrently.

    c. All frequency requests are subject to NASA Lunar Spectrum Manager review and completion of an interagency technical pre-coordination process prior to regulatory approval.

    d. Transmit authority of the pre-coordinated spectrum uses will be subject to licensing approval through the Federal Communications Commission (FCC) and compliant with ITU filing results.

4. Surface Wi-Fi Communications with EVA Suits (for Video, Science Data, EVA Suit Informatics, etc.), as defined in EVA-EXP-0067, HLS-xEVA System IRCD and other Wi-Fi entities, such as external or hand-held cameras and pre-positioned lunar assets (Lunar Terrain Vehicles, Pressurized Rovers, Surface Habitats, etc.):

    a. EVA suits are assumed to have a maximum on-foot traverse distance of up to 2 km radius from the HLS Integrated Lander on the lunar surface. Some distances may require the use of repeaters and/or other augmentations.

    b. EVA surface mobility assets, such as Lunar Terrain Vehicle or Pressurized Rover, are assumed to have a maximum traverse distance of up to 10 km radius from the HLS Integrated Lander on the lunar surface. Communications over these distances could involve the use of repeaters and/or other augmentations.

    c. Wi-Fi links should have data rates sufficient to convey full-resolution video streams from multiple sources (EVA suits, handheld camera, lunar assets, etc.) to the HLS Integrated Lander.

    d. Wi-Fi Frequency band: 5 GHz Band (preferred). Per EVA-EXP-0067, the EVA suits will utilize the 5 GHz Wi-Fi band only. Use of the 2.4 GHz Wi-Fi band is an available option for other lunar surface assets.

e. All frequency requests are subject to NASA Lunar Spectrum Manager review and completion of an interagency technical pre-coordination process prior to regulatory approval.

f. Transmit authority of the pre-coordinated spectrum uses will be subject to licensing approval through the Federal Communications Commission (FCC) and compliant with ITU filing results.

5. UHF Communications with EVA Crew Members for Astronaut Voice and Health Biometrics plus Suit Status Data & Telemetry, as defined in EVA-EXP-0067:

   a. EVA suits are assumed to have a maximum on-foot traverse distance of up to 2km radius from the HLS Integrated Lander on the lunar surface. Some distances or conditions may require the use of repeaters and/or other augmentations.

   b. EVA surface mobility assets, such as Lunar Terrain Vehicle or Pressurized Rover, are assumed to have a maximum traverse distance of up to 10 km radius from the HLS Integrated Lander on the lunar surface. Communications over these distances could involve the use of repeaters and/or other augmentations.

   c. All frequency requests are subject to NASA Lunar Spectrum Manager review and completion of an interagency technical pre-coordination process prior to regulatory approval.

   d. Transmit authority of the pre-coordinated spectrum uses will be subject to licensing approval through the Federal Communications Commission (FCC) and compliant with ITU filing results.

6. External Gateway Wi-Fi Communications for data transfer when in close proximity with the HLS Integrated Lander (in NRHO):

   a. “Best Effort” 5 GHz-band service, for non-critical data and telemetry applications, such as video transfer.

   b. All frequency requests are subject to NASA Lunar Spectrum Manager review and completion of an interagency technical pre-coordination process prior to regulatory approval.

   c. Transmit authority of the pre-coordinated spectrum uses will be subject to licensing approval through the Federal Communications Commission (FCC) and compliant with ITU filing results.

4.3.1 ICSIS Communications System Interoperability Standards

NASA/HEO has baselined HEOMD-003-02 International Communications System Interoperability Standards (ICSIS), revision A document for the HLS Program. The purpose of the ICSIS revision A standard is to define the functional, interface, and performance standards necessary to support interoperable and compatible communications between human exploration space-based platforms/vehicles, ground infrastructure, and other space and surface vehicles for human exploration in cislunar space (includes space transit, lunar orbit, and lunar surface segments).

For the HLS Provider(s), some parts of ICSIS are required to ensure communications interoperability. For example, the Consultative Committee for Space Data Systems (CCSDS) protocols & encryption algorithms for Orion and Gateway compatibility are required—see the applicable HLS Integrated Lander-to-Gateway Radio Frequency Interface Control Document(s) for the necessary details and applicable portions specific to Gateway. Other parts of the ICSIS document, such as using only specific frequency bands to communicate with Earth, are not required.

4.3.2 Lunar Spectrum / Frequency Selection

The lunar frequency recommendations, provided by the Space Frequency Coordination Group (SFCG), are shown in Table 4-1, below. Table 4-1 contains frequency bands that may be considered for specific mission requirements and operation in addition to those specified in Section 4.3; however, the SFCG recommendation of frequencies does not supersede NASA architecture requirements.

Table 4-1 Recommended Frequency Bands for Communications in the Lunar Region

Link	Frequency	
Earth to Lunar Orbit	2025-2110 7190-7235 22.55-23.15 40.0-40.5	MHz (Note 1), (Note 2) MHz GHz (Note 2) GHz
Lunar Orbit to Earth	2200-2290 8450-8500 25.5-27.0 37-38	MHz (Note 2) MHz GHz GHz (Note 3)
Earth to Lunar Surface	2025-2110 7190-7235 22.55-23.15	MHz (Note 1), (Note 2) MHz GHz
Lunar Surface to Earth	2200-2290 8450-8500 25.5-27.0	MHz (Note 2) MHz GHz
Lunar Orbit to Lunar Surface	390-405 2025-2110 23.15-23.55	MHz (Note 4) MHz (Note 2) GHz
Lunar Surface to Lunar Orbit	435-450 2200-2290 27.0-27.5	MHz (Note 4) MHz (Note 2) GHz
Lunar Orbit to Lunar Orbit	2025-2110 2200-2290 23.15-23.55 27.0-27.5	MHz (Note 2) MHz (Note 2) GHz GHz
Lunar Surface Wireless Network	390-405 410-420 435-450 2.400-2.480 2.5035-2.620 5.15-5.835 25.25-25.5 27.225-27.5	MHz (Note 4) MHz MHz (Note 4) GHz GHz GHz (Note 6) GHz GHz
Lunar Relay to Lunar Relay Cross Link	13.75-14 14.5-15.35	GHz GHz

Table 4-1 Recommended Frequency Bands for Communications in the Lunar Region

Link	Frequency
	23.15-23.55 GHz 27.0-27.5 GHz 37-38 GHz (Note 3) 40-40.5 GHz
Amateur Radio Operation, Earth-to-Lunar Orbit	144-146 MHz 435-438 MHz (Note 5) 2.4-2.45 GHz (Note 5) 5.65-5.67 GHz (Note 5)
Amateur Radio Operations, Lunar Orbit-to-Earth	144-146 MHz (Note 4) 435-438 MHz (Note 4), (Note 5) 10.45-10.5 GHz (Note 5)
Notes to Table 4-1 (Note 1) In making frequency assignments for uplinks in the 2025 – 2110 MHz band to missions operating in the lunar vicinity, careful frequency coordination should be performed, and measures taken to minimize interference to spacecraft operating in low-Earth orbit and L1/L2. (Note 2) In these communication frequency bands, position and navigation information may be contained in integrated ranging signals. However broadcast signals intended for PNT in the lunar region should use the frequency bands specified in Table 2 of SFCG Rec.14-2R5. (Note 3) 37-38 GHz band subject to SFCG Rec.14-2R5. (Note 4) Frequencies to only be used outside the Shielded Zone of the Moon (SZM). (Note 5) These frequencies are allocated on a secondary basis only, except 435-438 MHz is allocated primary in Region 1 and secondary in Regions 2 and 3. (Note 6) 5.25-5.57 GHz is allocated to Space Research Service (SRS) (active) on a primary basis; use of these frequencies for communications in the lunar region is on a non-interference and unprotected basis to SRS (active).	

To protect radio astronomy observations in the shielded zone of the moon (SZM), the following International Telecommunication Union (ITU) Radio Regulations (RR) and recommendation apply:

- ITU RR Nos. 22.22 – 22.25 prohibits emissions causing harmful interference to radio astronomy observations and other users of passive services in the SZM in the entire frequency spectrum except frequency bands allocated to space science services supporting active sensing and radio communications applications.
- ITU Recommendation: Necessary transmission in the SZM shall ensure operation in the properly allocated frequency bands and prevent harmful interference to radio astronomy observation in the SZM.

All HLS spectrum activities, including spectrum planning, coordination, and licensing, should be coordinated through the NASA Lunar Spectrum manager and the Federal Communications Commission (FCC) and ITU.

4.4 COMMUNICATIONS PRIVACY

Certain voice, video, data and/or text sessions will need to be kept private for crew medical conferences or family voice/video calls or texts, crew health data (such as EVA) This can be accomplished via encryption, via data routing, or a combination of the two. Limited privacy can be achieved by employing protected data transport at lower layers and restricting distribution. Virtual channel assignment over Consultative Committee for Space Data Systems (CCSDS) RF links is not, by itself, an effective method of ensuring privacy, although it can help with data routing. Metadata flags, commonly used in the music industry (MPEG3 ID3V2.X), can be used for the description of voice data. These flags may be used to indicate the type of conversation (e.g., family, or medical conference).

For voice communications, the person who is speaking or listening in a voice loop must have the required access permissions (role), user ID and password to permit logging into the voice system. If Voice over Internet Protocol (VoIP) is used, the transmission of the voice data must fulfill the same security requirements as the transmission of data in an IP network.

4.4.1 Voice Channel Segregation, Desegregation, and Audio Loops

All Artemis Elements (i.e., the HLS Integrated Lander, Orion, Gateway, Mission Systems) need the capability to mix (multiplex or de-multiplex) all audio streams into a single 'Master Channel' audio feed/loop for increased situational awareness when performing cross-program operations, such as Rendezvous, Proximity Operations, and Docking (RPOD), so that every crew member can communicate at the same time on the same voice loop. Conversely, all Artemis Elements should also have the ability to segregate audio channels, when necessary for privacy, or to aid in focusing on a particular task or duty, and/or to increase communication efficiency when needed for separate but concurrent tasks. For example, consider the case when there are seven active voice channels during a particular mission segment (such as: docked operations in lunar orbit with a 2-crew member EVA). Each of the four Astronauts has a separate voice channel, while there are three voice channels to Mission Control Center (MCC) at that particular point in time. For efficiency, the HLS Integrated Lander audio system should have the capability & flexibility to configure the channels and voice loops as follows (*Example setup and one of many possibilities*):

- Voice Loop 1: Comprised of Astronaut 1 and MCC 1, for the HLS Integrated Lander internal operations (configuring an on-board instrument)
- Voice Loop 2: Comprised of Astronaut 2 and MCC 2, for the HLS Integrated Lander internal operations (private medical conference)
- Voice Loop 3: Comprised of EVA 3 and EVA 4, and MCC 3, for the HLS Integrated Lander external EVA operations
- Voice Loop 4: Ability of a crew member inside the HLS Integrated Lander, or from Mission Systems to tie Voice Loop 1 and Voice Loop 3 together, for inside/outside communications.

With this type of communications loop functionality, it is possible to have three totally separate operations occurring concurrently yet be flexible enough to allow reconfiguration as/when needs change. This is especially true for DRM-002 which is an extended surface excursion mission that will leverage pre-placed assets at the lunar South Pole to support four crew members for a longer duration surface mission.

4.5 MOTION VIDEO IMAGERY DRIVER FOR RF LINK DATA RATES

NASA will be providing the HLS Astronauts with one or more hand-held cameras for use during the mission. While the specific camera(s) have not been chosen, desired characteristics include being capable of recording and live-streaming high-quality stills (>20 Mega-pixels) and capable of recording and live-streaming high-quality video motion imagery (2160p30 4:2:2 UHD 4K or 1080p30 FHD, user-selectable). It is expected that both still and video imagery will be broadcasted back live from the lunar surface (and at other times, e.g., while docking/undocking). This will require a high-rate, wide-bandwidth downlink, likely using Ka-Band, from the HLS Integrated Lander to Earth. In addition, the HLS Integrated Lander should have the ability to receive uplinked video from Earth for video/medical/engineering conference use. This will require a sufficiently-high-rate uplink to convey at least one channel of video from Earth to the HLS Integrated Lander.

Motion Imagery from the lunar surface—particularly during EVA operations—is expected to be the largest communications link data rate driver, during which time the HLS Integrated Lander needs the ability to live-stream no less than two (ideally six or more) simultaneous video feeds for a crew of two (2). Example motion imagery feeds are as follows:

- EV Astronaut #1 Helmet Video Camera for real-time situational awareness
- EV Astronaut #2 Helmet Video Camera for real-time situational awareness
- EV Astronaut #3 Helmet Video Camera for real-time situational awareness
- EV Astronaut #4 Helmet Video Camera for real-time situational awareness
- HLS Integrated Lander-mounted Ladder-Cam (climb down and footsteps on Moon) or portable Tripod-Cam for later EVAs
- HLS Integrated Lander-Mounted Cam (remote-control camera mounted atop the HLS Integrated Lander for third-person viewpoint & public affairs.)
- Hand-cam video streams (or still photo uploads) to verify lighting/focus/framing (EV Astronaut #1)
- Hand-cam video streams (or still photo uploads) to verify lighting/focus/framing (EV Astronaut #2)

Note: CCSDS Framing/Formatting can use a significant amount of overhead, so link raw data speeds will need to accommodate this, in all cases. Additional data rate margin will be needed for non-video related data, such as voice and telemetry/science/engineering/health/status/command data.

4.6 VARIOUS TYPES OF DATA RATES USED HEREIN

In this CONOPs, and only if the “data rate” or “symbol rate” is not otherwise specified, uses of ‘data rate’ herein will generally refer to location B, the “framed data rate”, and ‘’symbols” will generally refer to location C, the “FEC Symbol Rate” as shown below in Figure 4-2.

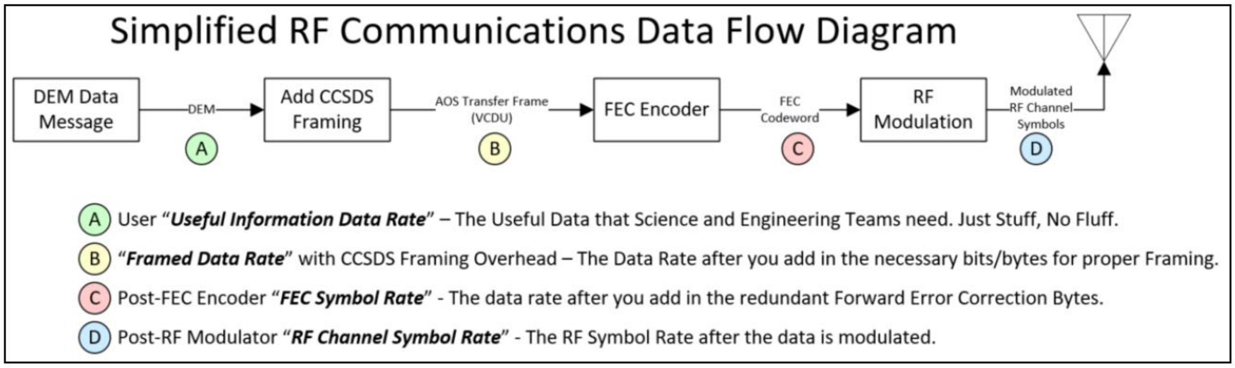


Figure 4-2 Illustration of various Data Rate and Symbol Rate Definitions used within Communication Systems

4.7 TRANSPONDER POINT A VS POINT B FUNCTIONALITY

Standard transponders operate in either ‘Point A’ mode (Standard Spacecraft User Mode) or ‘Point B’ mode (Ground Station Mode). The ‘Point B’ side of the link generates digital ranging codes, receives the ‘reflected’ codes back from the Point A user, and uses the delay & doppler to determine range and range-rate measurements. Typically, standard transponders operate in ‘Point A’ mode (Standard Spacecraft User Mode) only, while some specialized transponders can also operate in either ‘Point B’ mode or ‘Point A’ mode. Both Orion and Gateway Visiting Vehicle (VV) link transponders are capable of both ‘Point A’ and ‘Point B’ modes of operation with Orion preferring to operate in ‘Point B’ mode during RPOD operations. The Gateway Lunar System (LS) link system operates ‘Point B’ mode only.

5.0 GROUND STATION USE

The HLS Provider(s) may utilize any combination of government-provided and/or commercially-provided Ground Stations / Networks to support the sustaining Artemis mission objectives. It is desired that all high data rate communications links will, at a minimum, support the ability to transmit at least two live 2160p30 (4K UHD) video streams from the HLS Integrated Lander to Earth, and receive at least one 1080p30 live video stream from Earth to the HLS Integrated Lander, during all mission segments and with sufficient RF link margins.

<u>Space Communication and Navigation (SCaN)</u>

NASA's Space Communication and Navigation (SCaN) Program provides communications services that are essential to the operations of NASA's space flight missions. The two networks, Deep Space Network (DSN) and Near Space Network (NSN) provide support to over one hundred NASA and non-NASA missions. NASA’s Deep Space Network 70m and 34m diameter ground station antennas are heavily subscribed supporting current missions, so NASA’s Space Communication and Navigation (SCaN) organization does not recommend that the HLS Provider(s) rely solely upon either of those assets for nominal / routine lunar operations for sustaining lunar missions. Instead, SCaN recommends utilizing dedicated 18.3-meter diameter Lunar Exploration Ground Stations (LEGS) to support the Artemis Campaign, and designing links to close using no larger than 18.3 m assets.

DSN 34m Ground Stations:

While heavily utilized, the Deep Space Network (DSN) ground-based 34-meter antennas provide the best value Direct with Earth (DWE) communication services for NASA missions operating in the Near Earth and Deep Space regions. There are three clusters of 34-m antennas located at: Goldstone, United States; Canberra, Australia; and Madrid, Spain.

18m LEGS Ground Stations:

The Lunar Exploration Ground Sites (LEGS) mission is to provide Direct-with-Earth (DWE) communication and navigation services, via 18.3-m antennas, for mission operations in the cislunar regime. The ground stations will utilize CCSDS modulation and coding schemes for forward and return link data to ensure cross-program compatibility. Specialized modulation and codes schemes, as well as user local equipment, are optional and will be evaluated on a case by case basis. Currently, there are plans for three sites at locations spaced equally around the Earth with candidate locations including White Sands, United States, Matjiesfontein, South Africa, and Canberra, Australia, with final determination made by SCaN. The first ground station is planned for planned for White Sands.

6.0 USE CASES

6.1 GATEWAY-BASED MISSION

Gateway will nominally be used as the Crew Staging Vehicle for missions in the sustaining phase. The Gateway is an assembly of elements/modules in cislunar orbit intended to serve as a solar-powered communications hub, science laboratory, and short-term habitation module in support of landing astronauts on the Moon. Early configurations of the Gateway act as a waystation for the lunar surface mission, allowing the docking of Orion and checkout of HLS Integrated Lander systems, as well as providing a temporary home for the crew who remains in orbit during the surface sortie.

The Gateway Communications System that supports Gateway – Visiting Vehicle (VV) communications is located on the Habitation and Logistics Outpost (HALO) and is defined in the GP 10045-01 Interface Requirements Document (IRD) . Additional antennas will be located on the Power Propulsion Element (PPE) and may be located on other modules as needed to improve the coverage. The Gateway Communications System that supports Gateway – Lunar Systems (LS) communications, as defined in the GP 10046-01 IRD, is located on the Power Propulsion Element (PPE) and on the Habitation and Logistics Outpost (HALO).

Gateway is expected to support a minimum of three (3) simultaneous radio frequency (RF) communications links. Gateway will need to communicate simultaneously with a visiting vehicle, Earth, and a lunar surface asset, or with Earth, EVAs, lunar surface assets, etc. Therefore, the Gateway will have the necessary architecture framework and communications resources to support three or more simultaneous RF links. Gateway will communicate with Earth without placing constraints on flight attitudes during nominal operations. The Gateway Communications System that will have a direct downlink capability to Earth is located on the Power Propulsion Element (PPE).

The current HLS Concept of Operations is to communicate via high-rate Direct-with-Earth and/or Relayed-with-Earth links (*Note: Gateway could also be used to relay data back to Earth.*), and concurrently to Gateway. During all crewed mission phases, continuous communications is required; thus, the HLS Provider(s) must provide sufficient Ground Station and/or Relay satellite coverage such that no unplanned communications outages occur during crewed HLS operations. For an HLS Integrated Lander with a bidirectional link with Earth, the Provider(s) are free to choose the ground stations, number of links, and RF characteristics of each link. The HLS Integrated Lander must communicate directly with Gateway when within 400 km and either directly (i.e. via the Gateway Lunar Systems RF link) or indirectly with Gateway when outside of 400 km. Indirect communications may rely upon communication relays provided by NASA or non-NASA entities, including during lunar surface operations.

The HLS Program will prioritize selection of landing sites that maximize bidirectional, direct communications capability with Earth, but there could possibly be short time periods where the HLS Integrated Lander DWE link is blocked by lunar terrain or interrupted by multipath degradation. There will also be predictable time periods when Gateway is beyond the HLS Integrated Lander line-of-sight as it orbits the Moon, with the HLS Integrated Lander on the Lunar South Pole. Therefore, the HLS Integrated Lander will plan on using primarily DWE communications with Earth.

6.1.1 Gateway Capabilities

6.1.1.1 Overview

Gateway consists of two primary Radio Frequency Communication Systems that it will use to interact primarily with the HLS Integrated Lander: the Gateway-to-Visiting Vehicle (VV) communications link and Gateway-to-Lunar System (LS) communications link. The Gateway utilizes the following frequency bands for its primary communications links: S-band for low rate data transfers via the VV and LS links, Ka-band for high rate data transfers via the two-way DWE and LS links, and X-band for the Gateway's two-way DWE command and telemetry link. Summaries of the VV and LS RF links are provided below:

- **Gateway-to-Visiting Vehicle (VV) RF Link**:
  - "Short-Range" (<400 km) S-Band Communication System
  - Uses TDRS-Style Spread-Spectrum Communications (for Orion Compatibility—same links as Orion)
  - Hemi-Omni Coverage with Ranging for RPODU communications out to 400 km.

Note: The Gateway-to-VV RF requirements are governed by the GP 10045-01 Visiting Vehicle Radio Frequency Interface Requirements Document.

- **Gateway-to-Lunar Systems (LS) RF Link:**
  - "Long-Range" (up to 70,000 km) S-and Ka-Band Communication Systems
  - Uses DSN-Style Communications (PCM/PSK/PM with subcarrier, PCM/PM/bi-phase-L with residual carrier, and BPSK for S-band; filtered OQPSK for Ka-band)

- Gateway will use a steerable high gain antenna for PPE Ka-band, two dish steerable high-gain antennas for HALO Ka-band and S-band and, and two Low Gain Antennas (LGAs) for HALO S-band

- The HLS Integrated Lander may use S-Band Lunar Systems Link, or Ka-Band Lunar Systems Link, or both

- S-Band Frequency for Lunar Systems Link is different from S-Band Frequency for Visiting Vehicle link.

Note: The Gateway-to-LS RF requirements are governed by the GP 10046-01 Lunar Systems Radio Frequency Interface Requirements Document.

The Gateway can be used as a real-time (bent pipe) communications relay with Mission Systems, in addition to the HLS Integrated Lander two-way, direct communications with Earth. As shown in Figure 6-1, all HLS Integrated Lander communications with Earth will be two-way, DWE and/or RWE, but the HLS Integrated Lander can concurrently use Gateway, if within line of sight, to provide real-time voice situational awareness to the Gateway crew and transfer high rate data. During the HLS Integrated Lander RPODU with Gateway, where Gateway will use low-rate Gateway-HLS VV link, the HLS Integrated Lander must communicate directly with Gateway at ranges less than 400 km. Finally, the Gateway will provide a "best effort", external 5 GHz-Band Wi-Fi for data transfer when in close proximity with the HLS Integrated Lander. The external wireless link will be available for real-time video or other high data rate transfers, but external use of the 2.4 GHz band is precluded while Orion is docked to Gateway.

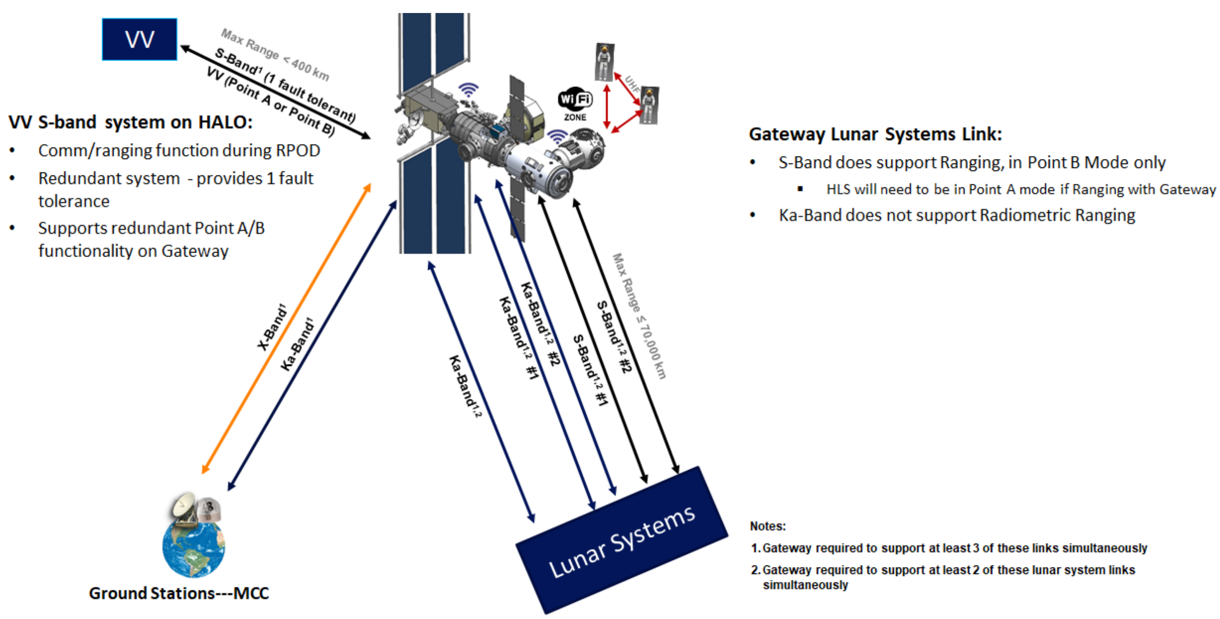


Figure 6-1 Gateway RF Comm Configuration/Capability

6.1.1.2 Gateway to HLS RF Interface Plane

The HLS Provider(s) should plan to operate in Point A Mode when communicating with Gateway. While Gateway is more flexible (for the VV RF link only), and will allow the HLS Integrated Lander to operate in either mode, the default case is for Gateway to be Point B. For S-Band RPODU and lunar surface communication, the Gateway Transponder will be in 'Point B Mode' (acting like a ground station), while the HLS Integrated Lander Transponder will be in 'Point A Mode' (standard spacecraft user mode). In Point B Mode, Gateway generates the PN ranging codes and calculates the range and range-rate from the HLS Integrated Lander Transponder's return signal. Since Gateway can provide radiometric ranging services over the S-Band Visiting Vehicle Link and/or the S-Band Lunar Systems Link, time tagged ranging data, direct from Gateway to the HLS Integrated Lander, is available for use as specified in GP 10045-01 and GP 10046-01. With Gateway in Point-B Mode, there's no need for the HLS Integrated Lander to provide a Point-B Transponder; therefore, the HLS Integrated Lander can use a standard-mode transponder. Per GP 10045-01, the high-rate VV link (6 Msps) does not provide the ranging capability.

6.1.1.2.1 Gateway to HLS LS Communication Link RF Interface Plane Description

The Gateway to the HLS Integrated Lander LS link is the Space-to-Space link between Gateway and the HLS Integrated Lander at ranges greater than 400 km. The Gateway-LS S-Band communication system can support two simultaneous S-band links and is designed to support Space-to-Space radiometric tracking to provide range and range-rate measurements in addition to low rate data exchange. Gateway generates and transmits a Pseudo-Random Noise (PN) ranging code phase modulated with forward link data to the carrier (residual carrier). The HLS Integrated Lander receives the forward link signal, filters it, turns it around and retransmits it with the telemetry data phase modulated to the carrier, and Gateway makes two-way measurements on the carrier frequency offset for range-rate measurement and the PN. Gateway will timestamp the range and range-rate measurements and send it to the HLS Integrated Lander at the needed rate via the LS data link. Gateway is the system in Point B mode and the Lunar system is in Point A mode. The Gateway-LS Ka-Band communication system is designed to support two simultaneous Ka-Band LS links for high rate data transfers and does not provide range and range-rate measurements. The Gateway to HLS Integrated Lander LS RF interface is shown in Figure 6-2.

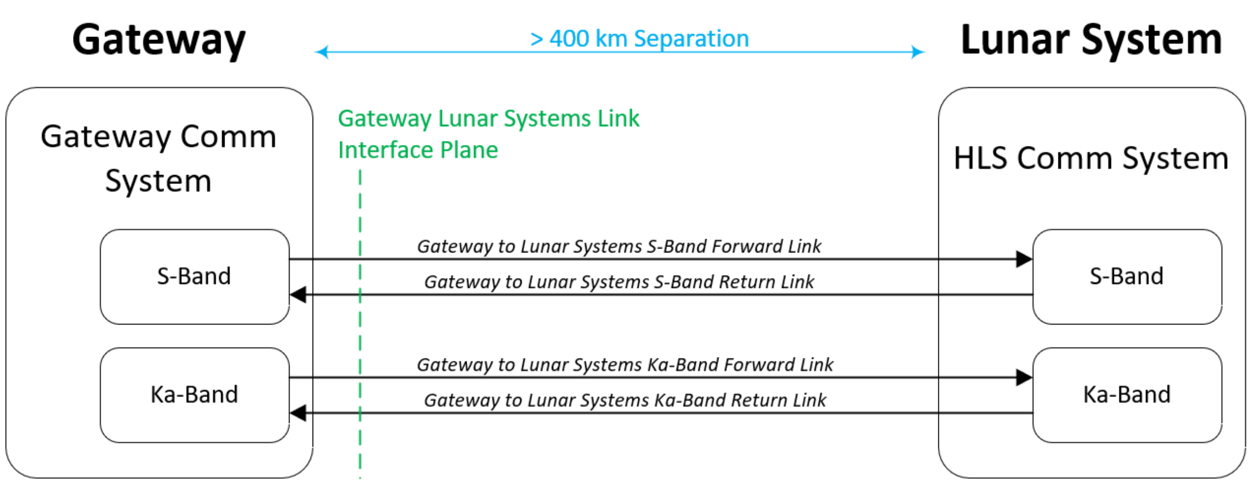


Figure 6-2 Gateway to HLS LS RF Link Interface

6.1.1.2.2 Gateway to HLS VV Communication Link RF Interface Plane Description

The Gateway to VV link is the Space-to-Space link between Gateway and its VVs such as Orion, HLS Integrated Lander elements, Logistics Module, etc. This link is compatible with the Orion Space-to-Space (i.e. rendezvous) Link and will be used during Orion and other VV rendezvous, proximity operations, and docking (RPOD) with Gateway.

The Gateway-VV Communication System is designed to support Space-to-Space radiometric tracking to provide range and range-rate measurements in addition to data exchange. The system, in Point B mode, generates and transmits a carrier frequency and Pseudo-Random Noise (PN) ranging code; the system in Point A mode, re-generates and transmits a carrier and PN code based on its received signal, and the Point B system makes two-way measurements on the carrier frequency offset and PN code delay it receives. The concept of operations between Gateway and the respective VV determines Point A/B roles. If Gateway is the Point B system, the VV is the Point A system and vice versa. The Gateway to VV RF interface plane is shown in Figure 6-3.

Figure 6-3 Gateway to HLS VV RF Link Interface

6.1.1.3 Video Motion Imagery Requirements between HLS and Gateway

During RPODU with Gateway, real-time 2160p30 (UHD/4K) video of the docking, undocking and departure may be transmitted from the HLS Integrated Lander to Earth on the HLS Integrated Lander Direct-with-Earth Link(s) and/or from Gateway to Earth via the Gateway Direct-with-Earth Link (s). Prior to opening of the airlock, and during crew transfer operations, the crew in Gateway will need critical video of the other side of any hatch, in addition to the hatch window (per HLS-RQMT-006), prior to opening the hatch to aid the crew in determining environmental safety. Video imagery could be sent via the Visiting Vehicle RF Link, Wi-Fi Link, hardline Ethernet, etc., but one possible option for relaying HLS Integrated Lander-generated video to a crew aboard Gateway would be to have the Gateway crew use an HLS Integrated Lander-provided Tablet Computer, connect it to HLS Integrated Lander-based Wi-Fi service, and have the HLS Integrated Lander serve the video stream to the HLS tablet aboard Gateway. Using this method would eliminate the need to modify or interface with Gateway and would keep all HLS Integrated Lander-generated video within the HLS Integrated Lander system boundary.

Note: The external Gateway Wi-Fi wireless system provides "best effort" (not guaranteed) availability.

6.2 CONTINGENCY DOCKING WITH ORION

In order to protect for the inability of the HLS Integrated Lander to dock with the Gateway on return and transfer the crew to Orion through Gateway, the HLS Integrated Lander must have the ability to change the docking sequence with Gateway to Orion. In this contingency case, the assumption is a healthy HLS Integrated Lander and Orion can perform proximity operations, docking and undocking to provide a backup means to save the HLS crew. The crew on Gateway will ingress Orion, perform all tasks necessary to safely undock with Gateway including hatch closure, suit donning, RPODU sensor installation, etc. The HLS Integrated Lander will hold position, including proper attitude to support Orion docking, in a safe range from Gateway. Orion will perform chasing with the HLS Integrated Lander as the target vehicle. Once hard docking is confirmed, the HLS Integrated Lander will pressurize the docking vestibule, the HLS crew will safe the HLS Integrated Lander, transfer to Orion including lunar samples and any needed consumables, and then prepare for undocking.

To support this DRM-001 scenario, the HLS Integrated Lander will need to allocate functions for chaser and target RPODU roles and provide a docking system compatible with both Gateway and Orion. For DRM-002, where all four crew members are expected to be on the HLS Integrated Lander with no crew on Gateway and Orion, the HLS Integrated Lander will need to consider implications of existing Orion RPODU capability that is only verified as a crewed, chaser.

6.2.1 Orion Capabilities

6.2.1.1 Overview

The Orion (Multi-Purpose Crew Vehicle, MPCV) will be used to safely transport crew and cargo from Earth to Beyond Earth Orbit (BEO) destinations and return. The Orion will be outfitted with the necessary equipment such as a docking system, Guidance, Navigation, and Control (GN&C), avionics, and communications equipment to carry a crew of 4 for a maximum of 21 active days. The Orion interface serves both physical and data exchange functions. The Orion consists of a Crew Module (CM), a Service Module (SM), a Spacecraft Adaptor (SA), and a Launch Abort System (LAS). The CM provides a habitable pressurized volume to support the crew during transport to LEO and BEO destinations and the return to Earth's surface.

The Orion communicates in S-Band only and has no X-Band or K/Ka-Band capability. The Orion S-band Proximity System uses a low-rate, Tracking and Data Relay Satellite (TDRS)-style modulation and does not have a real-time communications relay capability. The Orion communications coverage around the vehicle is nearly spherical with four Phased Array Antennas (PAAs) on the Crew Module (CM) that point forward, and two PAAs that point aft. Thus, there are small coverage cutouts off the tail of the vehicle.

During RPOD proximity operations (ranges less than or equal to 800 km), the Orion Transponder is planned to be in 'Point B' mode, while the HLS Integrated Lander Transponder will be in 'Point A' mode. Orion is capable of operating in 'Point A' mode, but the Orion Program desires to operate in 'Point B' mode for all S-Band crosslinks with the HLS Integrated Lander. If the HLS Integrated Lander requests ranging data, Orion will send the time-tagged data direct to the HLS Integrated

Lander after computation and with latency ≤ 3 seconds. Figure 6-4 defines the Orion to HLS Integrated Lander RF Interface Plane.

Note: Transmission of Orion centerline camera data from Orion to the HLS Integrated Lander may require changes to Orion's existing flight software. In addition, the capability would only be available at very close ranges and would incur a communications outage to swap operating modes, assuming the HLS Integrated Lander is in 'Point A' mode and Orion is in 'Point B mode' during initial RPOD operations.

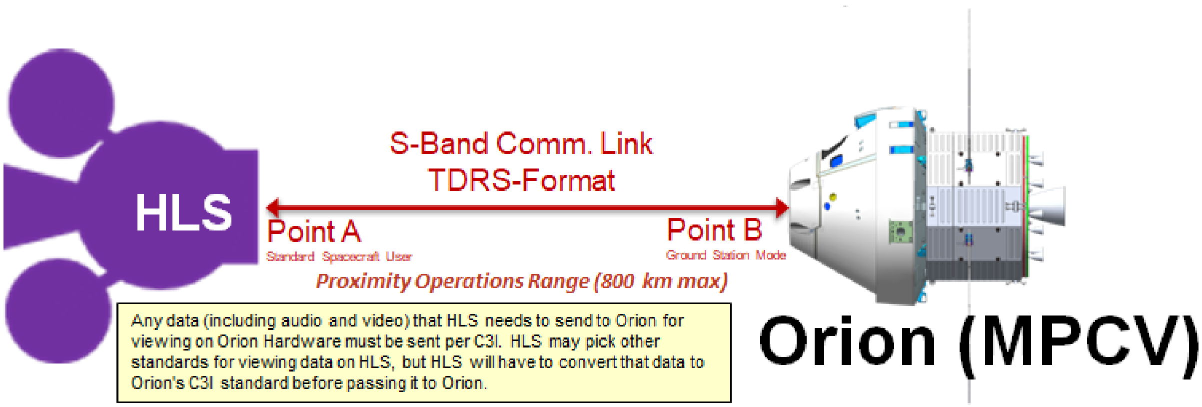


Figure 6-4 Orion to HLS Proximity Operations RF Interface Plane

During the contingency docking with Orion, all real-time, continuous HLS Integrated Lander communications with Earth will be DWE, RWE, and/or via Gateway. In addition, the Orion S-Band Proximity Communications System can support communications with ranging capability at distances up to 800 km. The current HLS Concept of Operations is to communicate high-rate data Direct with Earth (DWE) and simultaneously low-rate (30.5 kbps supporting voice and ~20 kbps of data) to Orion within range.

6.2.2 Contingency Docking Specific Constraints

The Orion attitude will be tail-to-sun (within a 20 degree half angle pyramid from the Orion –X body axis to the sun) to remain thermally and power stable, during rendezvous, proximity ops, docking, and undocking (RPODU) and during docked operations. Excursions outside this range are limited to three (3) hours. If Orion has deviated from tail-to-sun for the full 3 hours, Orion must remain in the tail-to-sun attitude for a minimum of 10 hours between deviations. Orion Attitudes can affect stack attitudes and Orion antenna-pointing characteristics.

When the HLS Integrated Lander transfers data to Orion, all data (precluding Wi-Fi video) must be sent per Orion's Command, Control, Communications, and Intelligence (C^3I) standard, meaning the HLS Integrated Lander will have to convert the HLS Integrated Lander data to Orion's C^3I standard before passing it to Orion. Conversely, when Orion sends data to the HLS Integrated Lander, the HLS Integrated Lander must perform any necessary data conversions. For video, Orion uses H.264 compression. All Orion and NASA Docking System (NDS) communication to or from the HLS Integrated Lander will conform to the C^3I standard. Any conversion of Orion's traffic to a different standard for use internal to the HLS Integrated Lander will be performed by the HLS Integrated Lander.

7.0 SUSTAINING PHASE LUNAR LANDING SITE SELECTION

NASA has an ongoing lunar landing site selection activity to ensure that the Human Lander Systems can land in lunar locations that support the sustaining mission phase objectives. The landing criteria will be significantly different from that used for the initial phase missions given the lunar infrastructure in place to support more ambitious design reference missions, including non-polar landing sites. In general, some key sustaining phase land site characteristics for consideration should include, but are not limited to, the following:

- Reasonable surface slopes to ensure the landers can land safely without fear of tip-over and to ensure astronauts can help self-level the lander (adjustable legs) to within 8˚ of the horizontal plane—preferably 5˚—for normal sleeping and crew activities.

- Reasonable surface traverses for EVA astronauts—meaning slopes from the HLS Integrated Lander to the objective—that are less than a 20˚ so the astronauts can safely walk without fear of falling down a hill/slope.

- Sufficient solar lighting to provide power to solar cells and panels. In some cases, the light will be coming in nearly horizontal making landing and EVA surface traverses potentially difficult. Therefore, lighting is a major consideration for power and astronaut visibility.

- Sufficient radio frequency communication line-of-sight back to Earth, CSV, and/or communications relays in lunar orbit. Depending on the landing site, the communications elevation angles could be less than 7˚above the horizon. In addition, lunar libration ("Moon wobble") will move the lunar south pole alternately in and out of line-of-sight with Earth every 2 weeks (assuming a south polar landing site).

- Sufficient radio frequency communications link performance to xEVA system, Artemis Base Camp, LTV, and/or Pressurized Rover. Surface terrain can induce multipath reflections due to the non-spherical nature of the lunar surface, and so the landing locations will need to be coordinated with the locations of other Artemis nodes and planned traverses of surface vehicles and astronauts.

It is critical that a landing site and landing time be chosen to allow for sufficient communications and lighting. NASA will specify landing time/location.

Figure 7-1 is a lunar landing site map analysis example displaying suitable landing locations near the lunar South Pole. Red areas represent regions of scientific interest, blue/green areas indicate suitable landing locations, and white circles have 2km radius and represent maximum EVA distance (on foot).

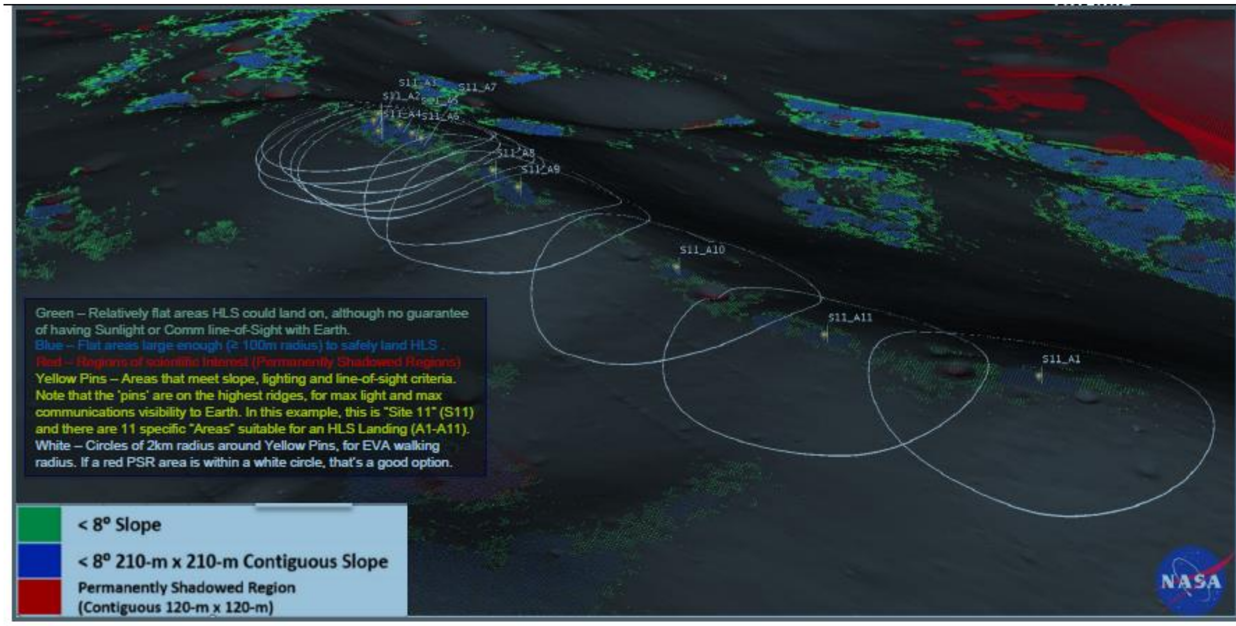


Figure 7-1 Lunar Landing Site Map Analysis (Example Only)

Figure 7-2 is an example lunar landing site location analysis showing time-windows-of-opportunity (areas in gray) for SLS/Orion launches times. These gray areas represent times where sufficient sunlight and DWE communications visibility support that specific landing site.

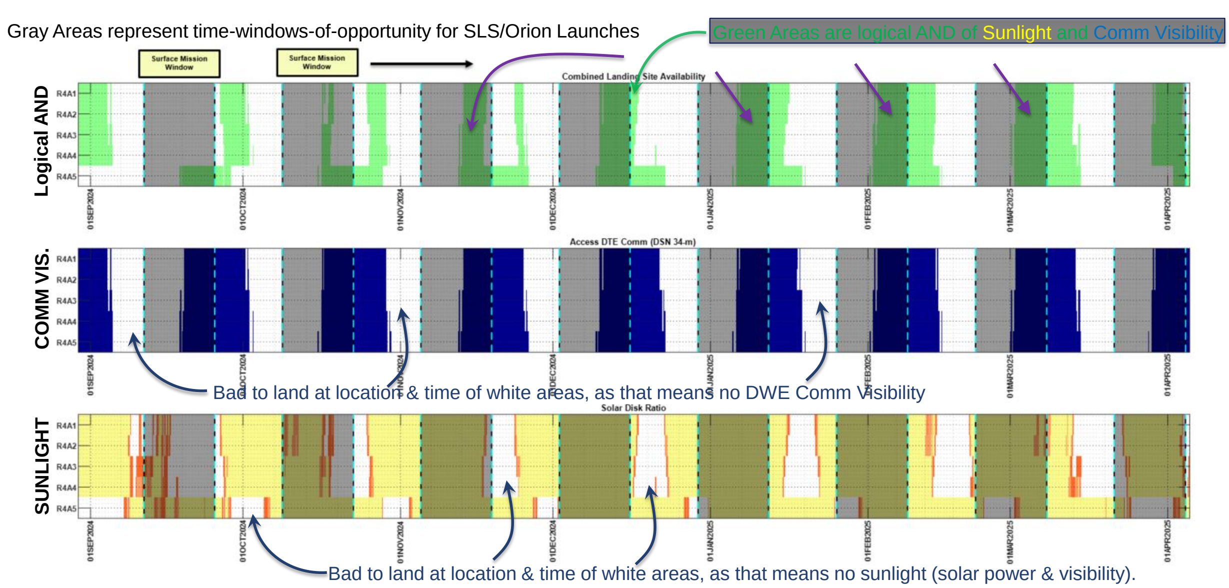


Figure 7-2 Lunar Landing Site Location Analysis (Example Only)

A list of possible landing locations is being compiled by the HLS Program Office and is being held as Controlled Unclassified Information (CUI) data because multiple countries have plans to land on the lunar surface in the Artemis-mission timeframes. The actual landing locations will be announced by NASA as the HLS Integrated Lander departs Near Rectilinear Halo Orbit for the lunar surface (possibly slightly earlier when Orion launches the crew for the specific mission). It is expected that the HLS Provider(s) will perform independent analyses for each potential landing site recommended by NASA.

8.0 LUNAR SURFACE MULTIPATH

In radio communications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The direct path between antennas is usually the ‘desired’ signal, whereas reflections that cause weaker, delayed signals to also reach the receiving antenna are generally regarded as undesirable signals. Receiving more than one signal often results in interference and can cause a communication channel to become too weak in certain areas to be received adequately, so multipath propagation can be detrimental to radio frequency communication systems.

On Earth, we experience this phenomenon regularly (whether we realize it or not), as a cellphone signal reflects off cars, trees, buildings, and even the Earth, on its way to the nearest Cell Tower. The receiving antenna receives the transmitted waves via multiple paths due to these reflections; therefore, the signal is received multiple times. In Figure 8-1, one “signal” is being transmitted, but due to reflections, the signal takes multiple paths to get to the receiving antenna, resulting in constructive and destructive interference at the receiving antenna (peaks & nulls).

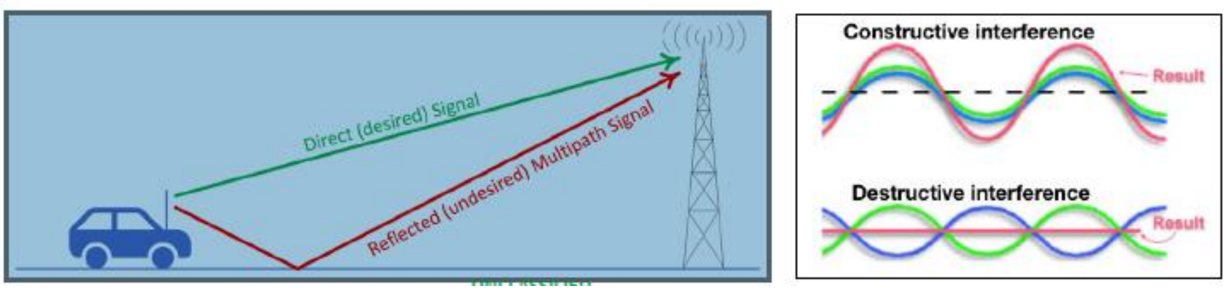


Figure 8-1 Radio frequency Multipath Degradation Overview

8.1 BASIC MULTIPATH EFFECTS ON PARABOLIC DISH ANTENNA DIRECTIVITY

For a 6” dish antenna pointed horizontally in free space, the antenna pattern has the following characteristics and is shown is Figure 8-2:

- Smooth Non-perturbed Antenna Pattern
- Excellent Directivity

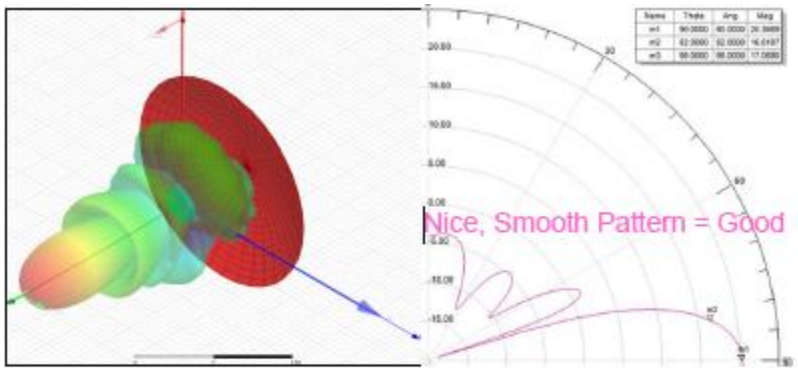


Figure 8-2 Multipath Effect on 6" Dish Antenna Pointed horizontally in free space.

For a 6" dish antenna pointed horizontally and 2m above lunar surface, the antenna pattern has the following characteristics and is shown is Figure 8-3:

- Note the rapid & deep nulls in the pattern's main lobe
- Null depths ~35 to >40 dB in some areas.

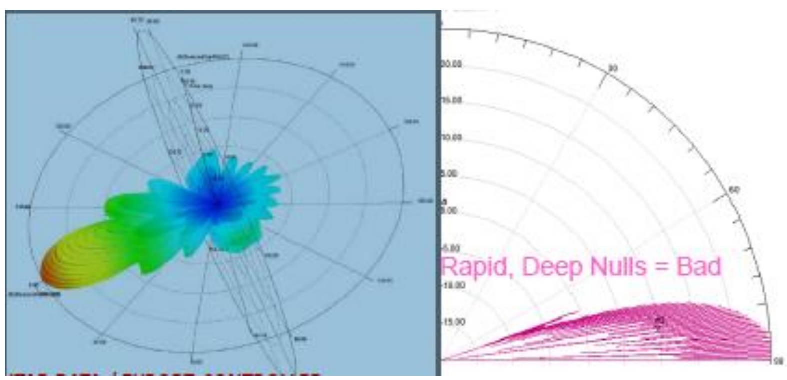


Figure 8-3 Multipath Effect on 6" Dish Antenna Pointed horizontally and 2m above Lunar Surface

8.2 COMPARISON OF 6" DISH IN FREE SPACE AND ON LUNAR SOUTH POLE

Computational Electromagnetics allows us to compare the main lobe directivity of a parabolic dish antenna in free space with the same dish antenna pointed nearly horizontally over the lunar south pole. As shown in Figure 8-4, antenna pattern null depths are deepest the closer the antenna is pointed toward horizontal. With the HLS Integrated Lander Antenna Elevation Angles not expected to exceed 6-7 degrees above the lunar horizon, the null depths shown here reach relative depths of about 50 db. However, this was a smooth surface model of the Moon; therefore, adding in surface roughness will lessen the null depth due to scattering, to about 12-20 dB, depending upon elevation angle.

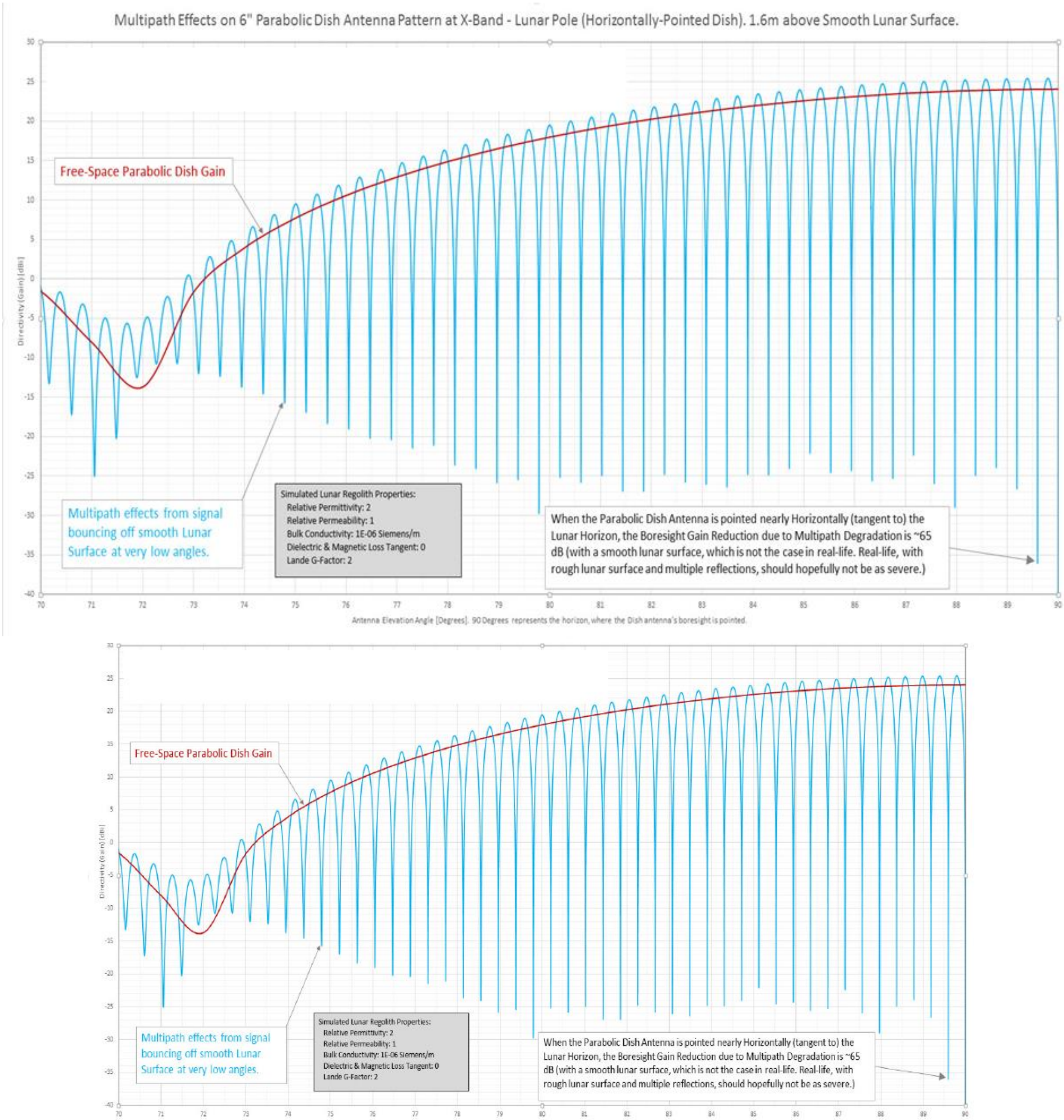


Figure 8-4 Multipath effects on 6" Parabolic Dish Antenna Pattern at X-Band – Lunar Pole (Horizontally-Pointed Dish). 1.6m above Smooth Lunar Surface.

8.3 LUNAR MULTIPATH DEGRADATION & MITIGATION

The HLS Provider(s) should be aware of, and take steps to mitigate a phenomenon known as Radio Frequency multipath degradation that can have a detrimental effect on line-of-sight communications between the lunar surface (and lunar orbit) and external communication assets such as the Earth and Orion. The direct path between antennas is usually the desired signal, whereas reflections (e.g. reflections off the lunar surface) that cause weaker, delayed signals to also reach the receiving antenna are undesirable signals. At the lunar poles, and depending upon where Artemis specifically lands, the Earth's apparent elevation will not rise more than about 6-7˚ above the local lunar horizon. Therefore, to transmit a signal to Earth, the HLS Integrated Lander will have to aim a directional antenna nearly horizontally to reach the Earth. This will place a significant amount of RF energy incident upon the lunar surface, and thus multipath reflections are of great concern. Multipath interference is also an issue in lunar orbit, per accounts from Apollo, GRAIL, LRO and LADEE. Analytical predictions can vary considerably based upon several factors; therefore, the HLS Integrated Lander should plan for a worst case condition. NASA can provide a statistical recommendation upon request.

9.0 GOVERNMENT FURNISHED PROPERTY (GFP) COMPATIBILITY

The following Government Furnished Property (GFP) information is per HLS-xEVA System IRCD, EVA-EXP-0067, Rev B.

The EVA Suits, including all accessories (e.g., built-in voice/data communication radios and antennas within the EVA Suits) are mandatory GFP, meaning the HLS Provider(s) must use them as part of the HLS sustaining missions. To provide for compatible communication between the HLS Integrated Lander and the EVA Suits, the HLS Provider(s) must provide:

- Compatible communication systems (HLS Integrated Lander to/from EVA Suits), including all required radio(s) and antenna(s) on the HLS Integrated Lander side. This system must provide for both HLS Integrated Lander-internal coverage/communication as well as HLS Integrated Lander-external coverage/communication:
  - HLS Integrated Lander-Internal (Intra-Vehicular Activity [IVA]) communication with EVA Suits may be used during doff and don operations inside the HLS Integrated Lander, as well as other operations, and must include full HLS Integrated Lander-internal coverage. During HLS Integrated Lander-internal operations while crew members are wearing EVA suits, hardline communication, radio frequency communication, and/or a combination of the two methods may be used as needed.
  - HLS Integrated Lander-external (Extra-Vehicular Activity [EVA]) communication with EVA suits is expected to be used continuously while the suits are outside of the HLS Integrated Lander. Therefore, the HLS Integrated Lander must provide for continuous, full-azimuthal coverage outside of the HLS Integrated Lander. Assuming flat lunar terrain, communication distances with EVA suits are expected out to 2km radius from the HLS Integrated Lander, and communication distances with Lunar Surface Assets (Rovers, Habitats, etc.) are expected out to 10km radius from the HLS Integrated Lander.
  - In order to convey at least two Ultra-High Definition (2160p30) signals from a crew camera at distances of 2-km for EVA suits, for example, the external comm system will likely have to support link speeds of ≥ 20 Mbits/sec which may necessitate use of directional antennas with pointing capability to track the EVA team as they traverse the surface.

- During initial formulation of the HLS Program, communication between the HLS Integrated Lander and EVA Suits was planned to use both UHF (primarily for voice comm) and Wi-Fi (primarily for data/video transfer). Given that there may be an entirely new EVA Suit architecture used for HLS Sustaining-Phase operations, it is currently unknown, at time of this writing (Dec 2021) how many different radios, and specific frequencies/bands that the EVA suits will use. The HLS Provider(s) will need to coordinate with the EVA Suits team to determine the appropriate radio(s) and antennas needed to meet this need, and a level of compatibility testing between them to ensure interoperability.

- The legacy Space-to-Space Communication System (SSCS) that the International Space Station used for communication with the EVA suits was a five (5)-user UHF system. It is possible that this system could continue to be used for the HLS Integrated Lander, but also possible that an entirely new system could be fielded.

- During lunar surface sorties, the EVA suit communication system will convey mission-critical EVA Suit data (i.e. voice communication, suit telemetry, biomedical (e.g. heart rate, etc.)) and real-time video from motion video/still cameras and hand-held science instruments back to the HLS Integrated Lander during EVA surface traverses. The HLS Integrated Lander will then live-stream this data back to Mission Systems on Earth via a sufficiently high-rate data link(s). In addition, Mission Systems may have need to send real-time configuration commands to EVA Suit cameras or systems. The HLS Integrated Lander will serve as the real-time, bi-directional data relay intermediary between the EVA suits and Mission Systems and/or the Crew Staging Vehicle in lunar orbit.

- It is possible that the HLS Integrated Lander repeaters or other communication system augmentations may be required to attain communication coverage out to the required distances.

10.0 WI-FI INFORMATION

The HLS Integrated Lander may use Wi-Fi extensively throughout the duration of the HLS Missions, and the HLS Provider(s) must provide for:

- Complete dual-band 802.11ac Wi-Fi signal coverage internal to the HLS Integrated Lander.
- Single-band, 90% spherical Wi-Fi signal coverage external to the HLS Integrated Lander, out to distances of 500m in free-space.
- Single-band, 99% azimuthal Wi-Fi signal coverage external to the HLS Integrated Lander, out to distances of 500m on the lunar surface, assuming flat lunar terrain.

If Wi-Fi ends up being one of the protocols required for EVA Suit communications, the requirement to provide for HLS Integrated Lander signal coverage may have already been met (or partially-met) as part of Section 9.0, above.

The three primary use-cases for Wi-Fi signals on the HLS Integrated Lander are as follows:

- HLS Integrated Lander-Internal Dual-band Wi-Fi Signals may be used in support of data transfers to/from hand-held crew devices such as tablets, cameras, computers, environmental monitors, etc.).
- HLS Integrated Lander-external Single-band (5 GHz) Wi-Fi signals may be used in free-space (NRHO) to support data and video transfer to/from other nearby vehicles, as opposed to using S-band proximity links for such purposes.
  - For example, say the Orion Crew is provided an HLS Integrated Lander-compatible Tablet Computer aboard Orion. As the uncrewed HLS Integrated Lander comes into Wi-Fi range, the Orion Crew connects the HLS Integrated Lander-compatible Tablet Computer to the HLS Integrated Lander Wi-Fi service (provided that HLS Integrated Lander Wi-Fi signals can penetrate the Orion spacecraft), so the Orion Crew can ascertain HLS Integrated Lander health, status, video, etc. Additionally, the HLS Tablet could be used to visually-verify safe conditions on the other side of an HLS Integrated Lander hatch before opening.
  - Note that on Space Station, Wi-Fi has already been successfully used in space to transfer rendezvous video at distances out to 600 meters.
  - For critical RPOD commands, the S-Band Proximity link would be used.
- HLS Integrated Lander-external Single-band (5 GHz) Wi-Fi signals may be used on the lunar surface by nearby external science experiments, wireless cameras, EVA tools, etc.
  - Even early HLS Sustaining phase missions are expected to fly external payloads from NASA/SMD and others which may need Wi-Fi to transfer data or to support startup before a DWE link is established.
  - Use of Wi-Fi does not preclude the use of Long Term Evolution (LTE) signals or other similar technologies for this function as lunar spectrum is set aside for LTE or other advanced surface communications capabilities.

11.0 DELAY TOLERANT NETWORKING (DTN)

Communicating from Earth to any spacecraft is a complex challenge, largely due to the extreme distances involved. When data are transmitted and received across thousands and even millions of miles, the delay and potential for disruption or data loss is significant. Delay/Disruption Tolerant Networking (DTN) is NASA’s solution to reliable internetworking for space missions.

For previous missions from low-Earth orbit to deep space, NASA has used point-to-point (direct) or single relay links to communicate with spacecraft; this operates much like the phone system by directly connecting two communication nodes. While this approach has been successful for previous missions, future exploration concepts will introduce much more complex communication needs, with data transfer between many nodes. These transmissions will need to operate like the Internet here on Earth – involving multiple hops via relay spacecraft and other intermediate nodes, creating the foundation for a LunaNet architecture. These multiple hop communication links may not always be continuously visible across all intermediate nodes, and so the DTN capabilities will allow for intermediate nodes to store-and-forward data when visibility between themselves and the next node in the sequence is present. Additionally, DTN allows for these multiple hop communication links that are bandwidth or power-constrained to decrease data rates on various segments to maintain link quality by storing the data stream until the entire message has been transmitted.

Like the terrestrial internet, the LunaNet will offer users a well-defined, standardized platform upon which to build a wide variety of applications by accessing end-to-end network services. The LunaNet will utilize the DTN protocol suite, which can be used in any scenario, including those with longer light times, frequent link disruptions, links that are limited to one direction, or links with high error rates, where conventional Internet Protocols (IP) fail.

The DTN protocol suite can operate in tandem with the terrestrial IP suite or it can operate independently. DTN provides assured delivery of data using automatic store-and-forward mechanisms. Each data packet that is received is forwarded immediately if possible but stored for future transmission if forwarding is not currently possible but is expected to be possible in the future. As a result, only the next hop needs to be available when using DTN. The DTN suite also contains network management, security, routing, and quality-of-service capabilities, which are similar to the capabilities provided by the terrestrial Internet suite.

Neither the Orion nor the Gateway Visiting Vehicle link support DTN since the ranges and latencies are not sufficient to benefit from DTN; in addition, the links are sufficiently robust. The Gateway does plan to support DTN on their Lunar Systems links once Gateway has reached full capabilities. Similarly, the envisioned Lunar Relay satellites provided by SCaN and future ground assets/segments are also planned to support DTN during the Sustaining Phase of HLS Missions.

12.0 INFORMATION SECURITY / COMMUNICATIONS SECURITY

In accordance with NASA-STD-1006 Space System Protection Standard, the HLS Integrated Lander must maintain command authority to prevent unauthorized access and to ensure data integrity. Unauthorized access could result in mission loss and/or damage to the HLS Integrated Lander and other space systems. Therefore, the HLS Integrated Lander will utilize NIST-certified AES 256-bit / GCM encryption, as specified in CCSDS 355.0-B-1 Space Data Link Security Protocol, for all HLS Integrated Lander RF uplink(s) and downlink(s)—exclusive of the UHF and Wi-Fi links, which will use their own communications security protocols—during each mission segment where RF communications is planned. In particular, encryption is required for the following RF Links:

- Direct-with-Earth uplink(s) and downlink(s)
- Gateway Visiting Vehicle uplink(s) and downlink(s)
- Gateway Lunar Systems uplink(s) and downlink(s)
- Orion Proximity link
- Relayed-with-Earth uplink(s) and downlink(s).

The purpose of the CCSDS 355.0-B-1 required standard is to specify the space data link security protocol for CCSDS data links. This protocol provides a security header and trailer along with associated procedures that may be used with the CCSDS Telemetry, Telecommand, and

Advanced Orbiting Systems Space Data Link Protocols to provide a structured method for applying data authentication and/or data confidentiality at the data link layer.

Note that the security provided by the CCSDS Space Data Link Security protocol can vary between Virtual Channels, if needed. For example, there could be some Virtual Channels with AES256/GCM security and some channels without, if there was a need to have one or more unencrypted Virtual Channels. The NASA reference baseline is to encrypt all virtual channels in both directions (uplink and downlink) using AES-256/GCM. The capability to operate in one of two unencrypted modes--authenticated unencrypted mode or un-authenticated security bypass mode—will be reserved for contingency operations only.

Finally, the HLS Program Threat & Vulnerability Assessment (TVA), performed at the request of the Office of the Chief Engineer, will analyze the HLS Integrated Lander for vulnerabilities, determine what significant threats exist (and are most likely to be encountered), and suggest steps or measures to be taken to protect HLS Integrated Lander assets and communication links. This classified Threat & Vulnerability Assessment (and subsequent classified Security Recommendation) will be researched and written by NASA and will drive the unclassified HLS Integrated Lander Communication System design.

13.0 SUSTAINING-PHASE MISSION

The HLS Integrated Lander is a vehicular system that supports the transport of logistics and mission support equipment from Earth to NRHO, transports crew members from Gateway in a NRHO to the lunar surface, enables the crew to perform EVA on the surface, and then safely returns the crew to Gateway for RTE. As lunar surface exploration evolves into the Sustaining Phase, more ambitious DRMs will be pursued. The Sustaining Phase missions will require the HLS Integrated Lander to support landing a crew of up to four (4), have the capability to land and operate at non-polar landing sites or for extended durations near the lunar south pole, and will have the capability of performing 8-hour EVAs to help further the advancement of surface goals. These missions will have enhanced up and down mass, darkness survival capability, longer EVA durations, and support a larger number of EVAs or transfer to other habitable elements. Sustaining Phase missions may include reusable elements from previous missions or have interactions with other systems in the lunar vicinity such as Lunar Rovers and Surface Habitats. Further information with regard to lunar surface assets can be found in HLS-IRD-008, HLS Integrated Lander to Lunar Surface Assets (LSA) IRD.

Figure 13-1 provides a government reference concept of operations diagram for the Sustaining Phase mission with Gateway as the CSV. While Figure 13-1 shows a three-element HLS Integrated Lander architecture, that is only one of many possible HLS Integrated Lander design solutions.

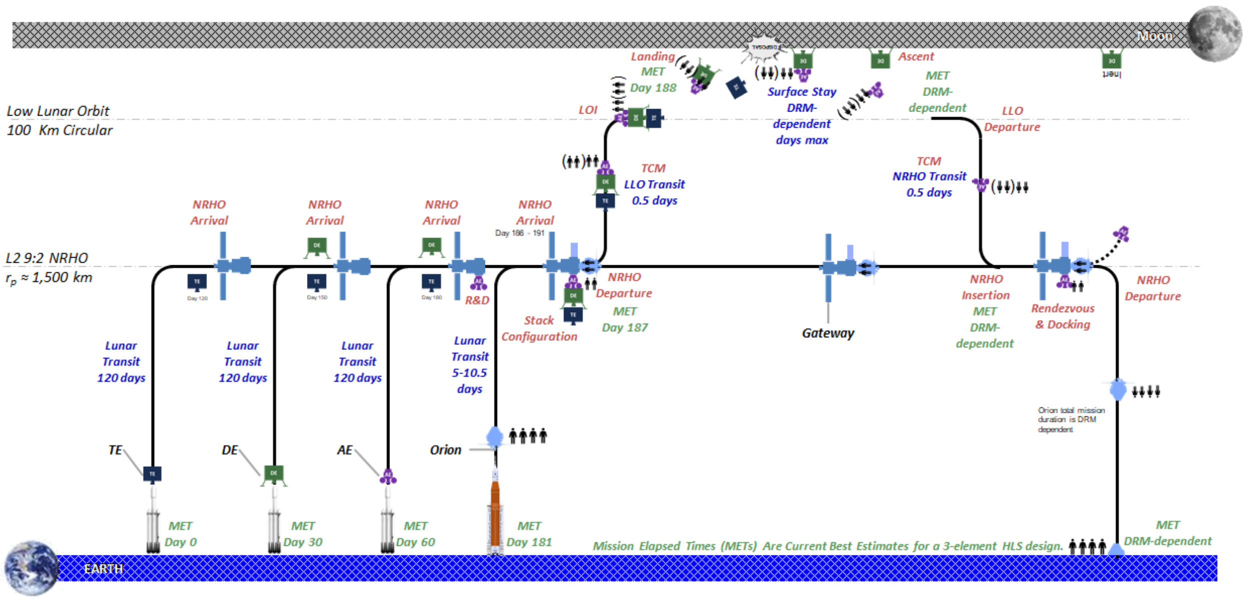


Figure 13-1 HLS Sustaining Phase mission – Gateway as CSV

13.1 MISSION SEGMENTS

This section describes each mission segment reference for the HLS Sustaining-Phase and are applicable for both 2-crew (DRM-001 and DRM-001b) or 4-crew missions (DRM-002) to the lunar surface.

13.1.1 HLS Pre-Launch Activities and Mission Overview

For the sustaining mission concept, the TE, DE and AE aggregate at and dock at the Crew Staging Vehicle (CSV) (Gateway in a Lunar Orbit [NRHO]) where crew from the CSV enter the AE. The TE provides propulsion to get the HLS Integrated Lander stack from the CSV to low lunar orbit, and the Descent Element provides the propulsion necessary for a soft lunar touchdown on the Moon's South Pole. The Ascent Element serves as the host platform for the crew, a habitation element for lunar surface EVA operations over DRM-dependent days, and the propulsion element necessary to transfer from the lunar surface back to the CSV. Figure 13-2 assumes separate commercial launch vehicle (CLV) launches per HLS Integrated Lander element.

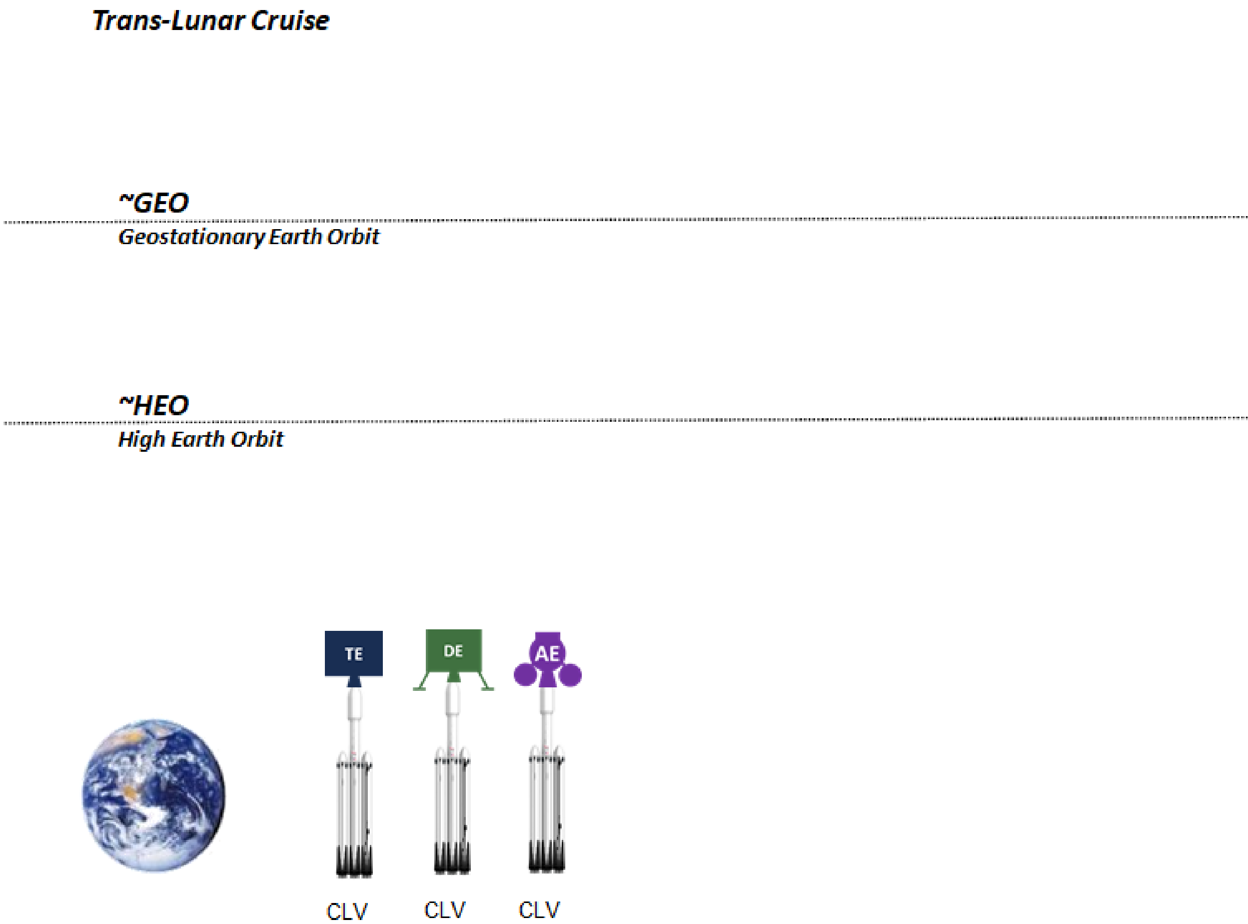


Figure 13-2 HLS Pre-Launch

13.1.2 Transfer Element Launch and Transit

Transfer Element (TE) Direct-with-Earth link(s) and Relayed-with-Earth link(s), when available, will provide forward link services, for commanding and ranging data transfers from Earth to the HLS Integrated Lander, and return link services, for video, health and status, and ranging data transfers from the HLS Integrated Lander to Earth, from launch vehicle separation through trans-lunar cruise as shown in Figure 13-3. During the trans-lunar cruise segment, and after initial test and check-out, the system must support continuous receive coverage, plus two-way coverage for all notable events and time periods (currently undefined), as required during trans-lunar cruise to the lunar vicinity (not necessarily NRHO). During this transit phase, Ballistic Lunar Transfers (of unmanned missions) may spend a portion of their trajectory significantly beyond the moon's orbit. Although lunar communication relays may be present, when spacecraft are outside of cislunar space (such as during transit phases), it is the responsibility of the spacecraft to ensure that its DWE links have sufficient margin(s) to maintain spacecraft operations, independent of lunar comm relays. Live video transmission is not required during this mission segment.

Upon arrival within cis-lunar space, Transfer Element Relayed-with-Earth link(s) will be available as a dissimilar communications path for command uplink, ranging, data, video, and status.

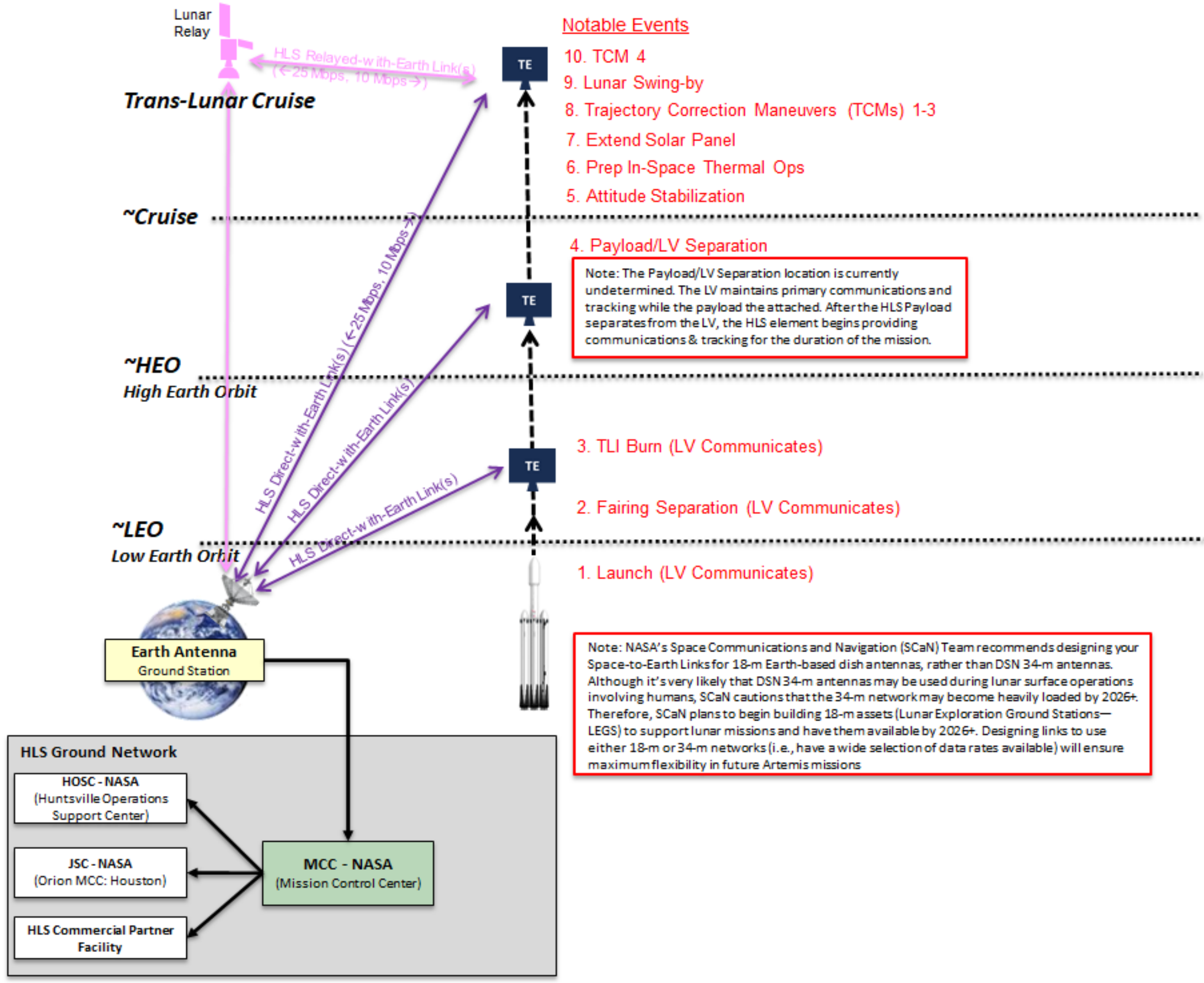


Figure 13-3 Transfer Element Launch and Transit

13.1.3 Descent Element Launch and Transit

Descent Element (DE) Direct-with-Earth link(s) and Relayed-with-Earth link(s), when available, will provide forward link services, for commanding and ranging data transfers from Earth to the HLS Integrated Lander, and return link services, for video, health and status, and ranging data transfers from the HLS Integrated Lander to Earth, from launch vehicle separation through trans-lunar cruise as shown in Figure 13-4. During the trans-lunar cruise segment, after initial test and check-out, the system must support continuous receive coverage, plus two-way coverage for all notable events and time periods (currently undefined), as required during trans-lunar cruise to the Moon. To support Public Affairs Office (PAO) coverage of Lunar North Pole Fly-by, as well as Rendezvous, Proximity Operations & Docking/Undocking (RPODU), the DE link(s) should be capable of transmitting at least 2160p30 (UHD) live video.

Upon arrival within cis-lunar space, Descent Element Relayed-with-Earth link(s) will be available as a dissimilar communications path for command uplink, ranging, data, video, and status.

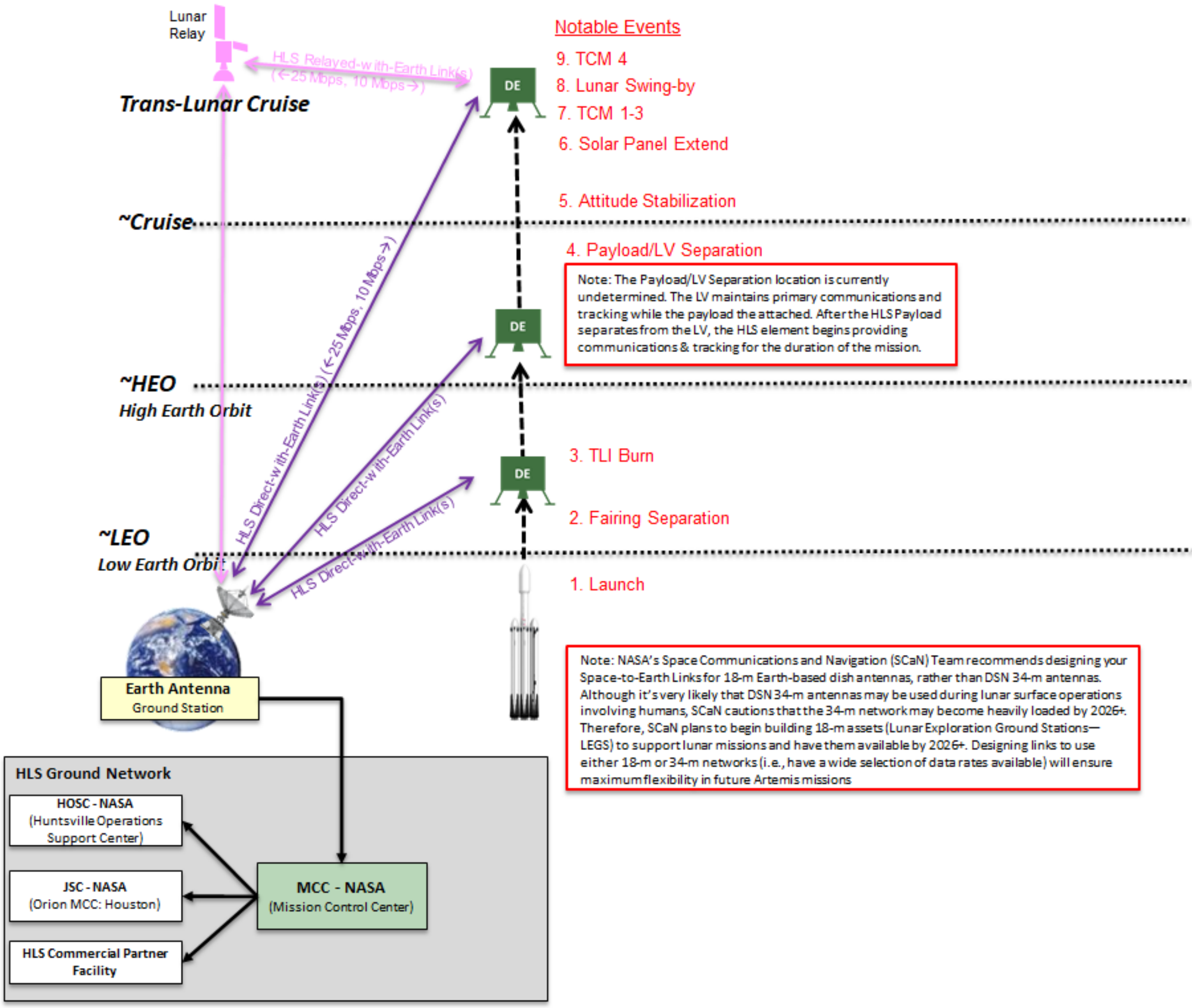


Figure 13-4 Descent Element Launch and Transit

13.1.4 Ascent Element Launch and Transit

Ascent Element (AE) Direct-with-Earth link(s) and Relayed-with-Earth link(s), when available, will provide forward link services, for commanding and ranging data transfers from Earth to the HLS Integrated Lander, and return link services, for video, health and status, and ranging data transfers from the HLS Integrated Lander to Earth, from launch vehicle separation through trans-lunar cruise as shown in Figure 13-5. During the trans-lunar cruise segment, after initial test and check-out, the system will support continuous receive coverage, plus two-way coverage for all notable events and time periods (currently undefined), as required during trans-lunar cruise to the Moon. To support PAO coverage of Lunar Fly-by—and later, for engineering video of docking operations, crew video, EVA operations, etc.—the AE Direct-with-Earth link(s) should be capable of transmitting real-time 2160p30 (UHD) video.

Upon arrival within cis-lunar space, Ascent Element Relayed-with-Earth link(s) will be available as a dissimilar communications path for command uplink, ranging, data, video, and status.

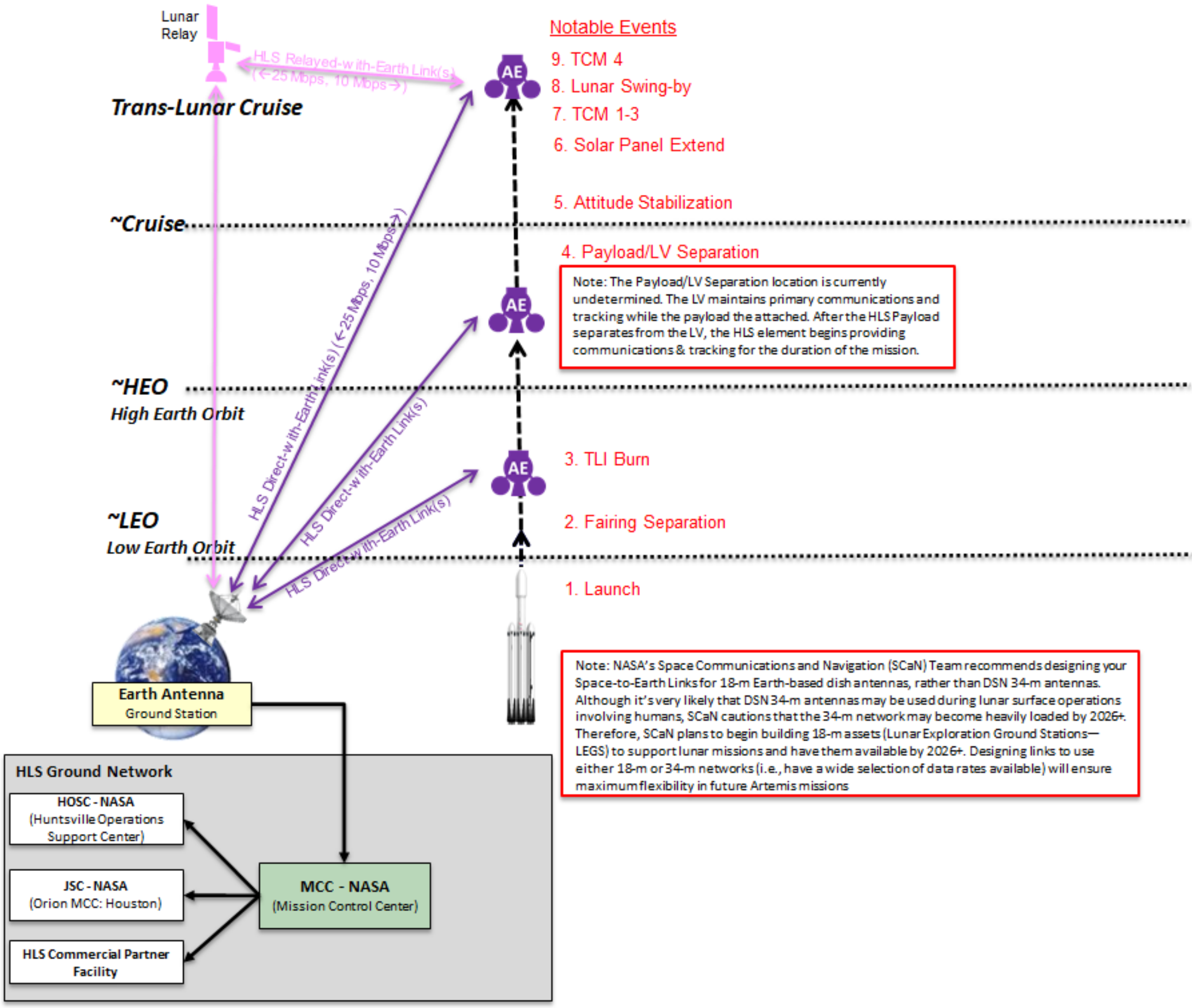


Figure 13-5 Ascent Element Launch and Transit

13.1.5 Gateway as Crew Staging Vehicle DRM

13.1.5.1 Simultaneous Transit Gateway

During a currently undefined time interval (perhaps weeks), the TE, DE and AE will all simultaneously be in transit to the Moon, and RF coverage is provided via dissimilar communication paths, i.e. the Direct-with-Earth link(s) and Relayed-with-Earth link(s) as shown in Figure 13-6. Each element will maintain continuous receive coverage from Earth (i.e. so Earth can always send commands) with continuous two-way coverage during individual notable events. In support of Trajectory Control Maneuvers (TCMs), continuous two-way ranging coverage is expected for a duration of ~8 hours pre-TCM and ~8 hours post-TCM. During simultaneous transit segment, it is anticipated that only one (1) HLS Integrated Lander element will transmit at a time enabling Earth to serially communicate with each element (i.e. one Earth antenna cycles between the HLS Integrated Lander elements as they cruise towards the Moon).

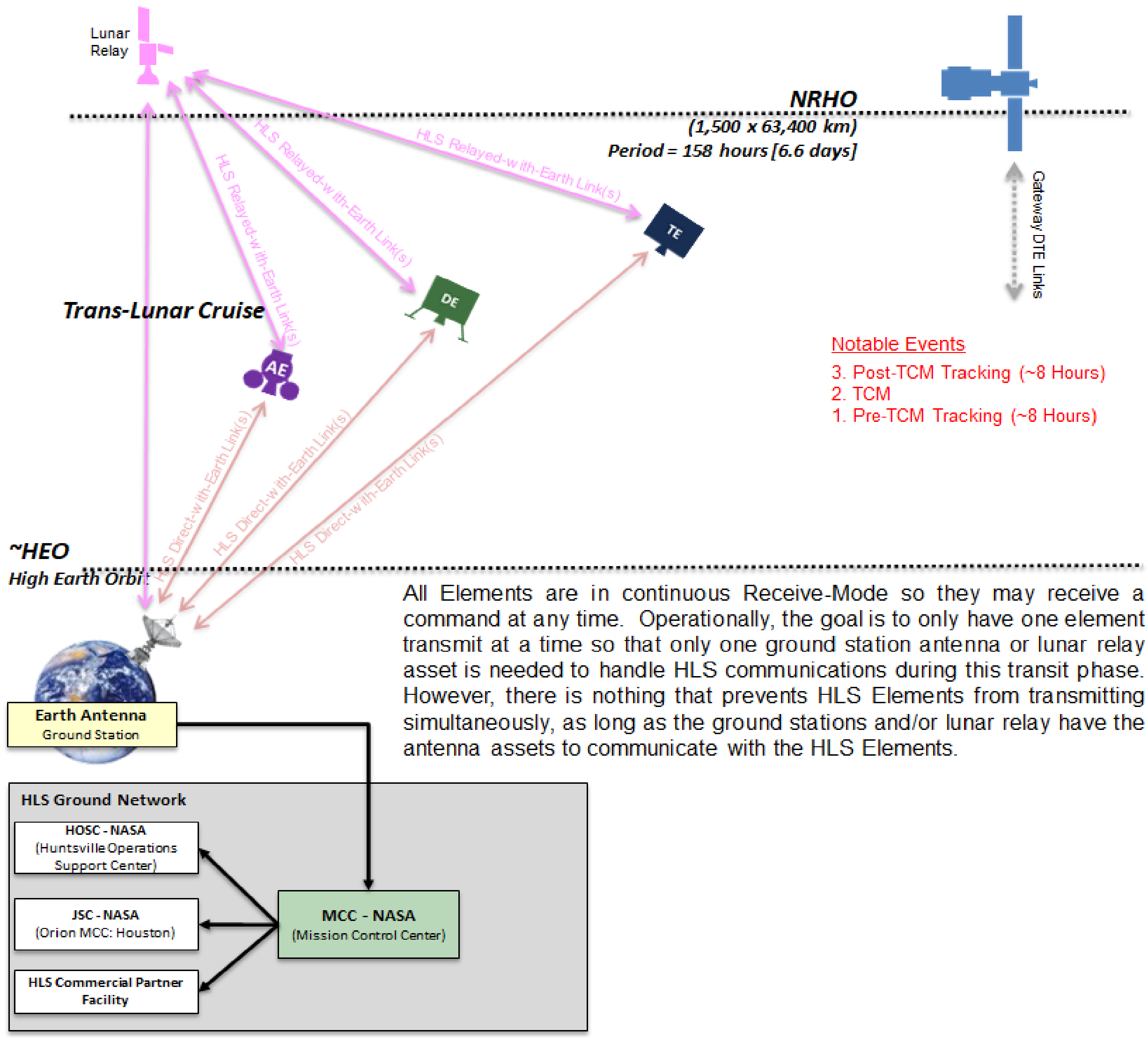


Figure 13-6 Simultaneous Transit

13.1.5.2 Transfer Vehicle Element (TVE) Arrival at NRHO

The TE maintains (periodic) link(s) with Earth, i.e. Direct-with-Earth link(s) and Relayed-with-Earth link(s), just as it did during cruise segment. Once TE approaches to within 400 km of Gateway, it also establishes an S-Band Visiting Vehicle link to CSV for ranging, status, and data transfer as shown in Figure 13-7. At this point, the TE enters “loiter” mode and “station-keeps” (parks) until the other of the HLS Integrated Lander elements (DE and AE) arrive.

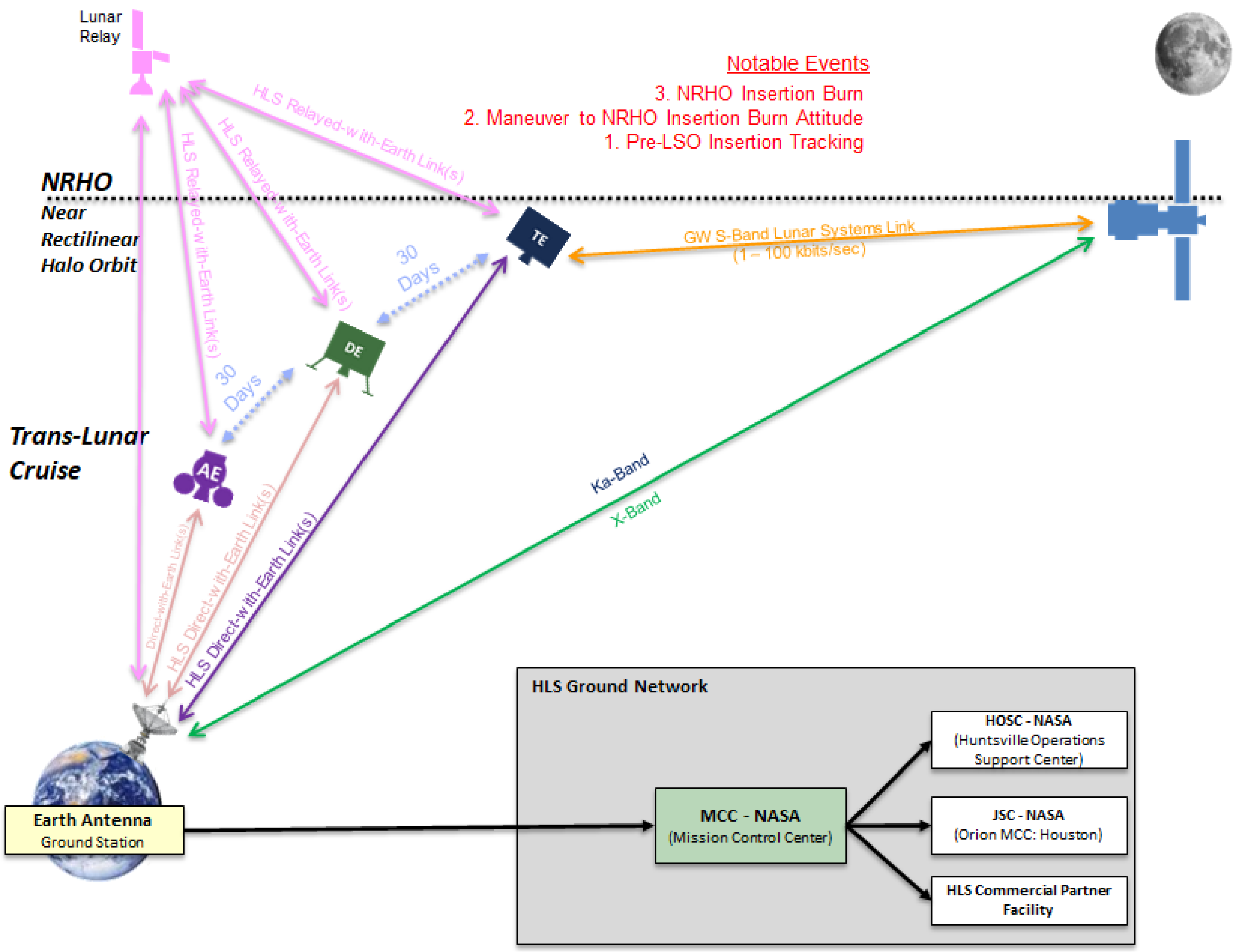


Figure 13-7 Transfer Vehicle Element (TVE) Arrival at NRHO

13.1.5.3 Descent Element (DE) Arrival at NRHO, Docking with TE

The DE continues to maintain Direct-with-Earth link(s) and/or Relayed-with-Earth link(s) to Earth for ranging and status. Upon entering NRHO, DE establishes a simultaneous Rendezvous Communication Link with TE for ranging, status and data as shown in Figure 13-8. DE transmits real-time video and telemetry as necessary during arrival and loiter. At this point, DE transmits telemetry to Earth as necessary during arrival and loiter / station-keeping.

Once within range of TE, DE & TE undergo final checks for docking. DE transmits telemetry and real-time 2160p30 (UHD) video to Earth as it approaches and docks with TE.

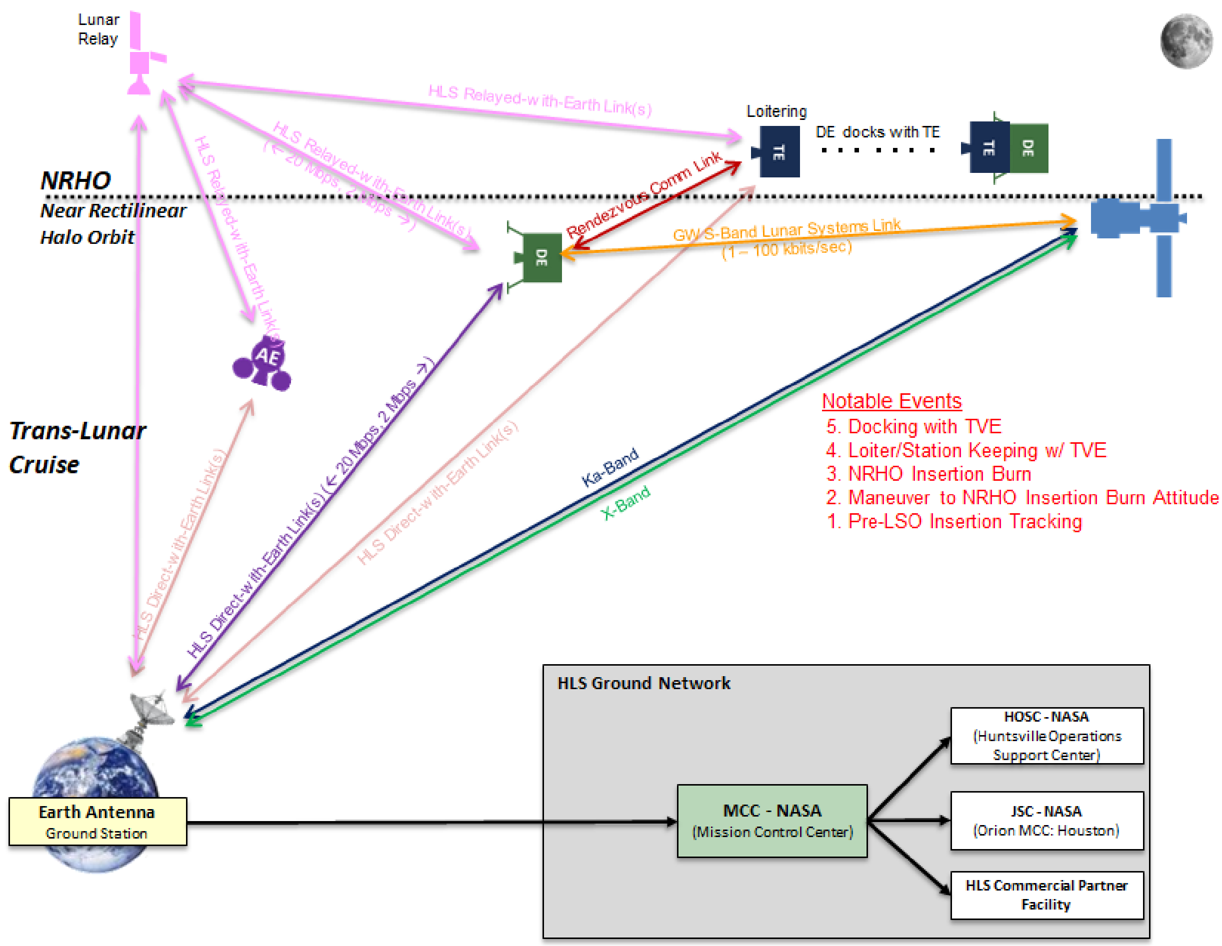


Figure 13-8 Descent Element (DE) Arrival at NRHO, Docking with TE

13.1.5.4 Ascent Element (AE) Arrival at NRHO, Docking with HLS Stack

The AE continues to maintain Direct-with-Earth link(s) and/or Relayed-with-Earth link(s) for ranging, video, data, and status. Upon entering NRHO, AE establishes simultaneous S-Band Rendezvous link with DE/TE Stack for ranging, status and data transfer as shown in Figure 13-9. The AE transmits telemetry to Earth as necessary during arrival and loiter / station-keeping.

Once within range of TE/DE Stack, all Elements undergo final checks for docking. The AE transmits telemetry and real-time 2160p30 (UHD) video to Earth as it approaches and docks with TE/DE Stack.

After docking, all HLS Integrated Lander elements undergo a full health & checkout period prior to beginning RPOD with Gateway.

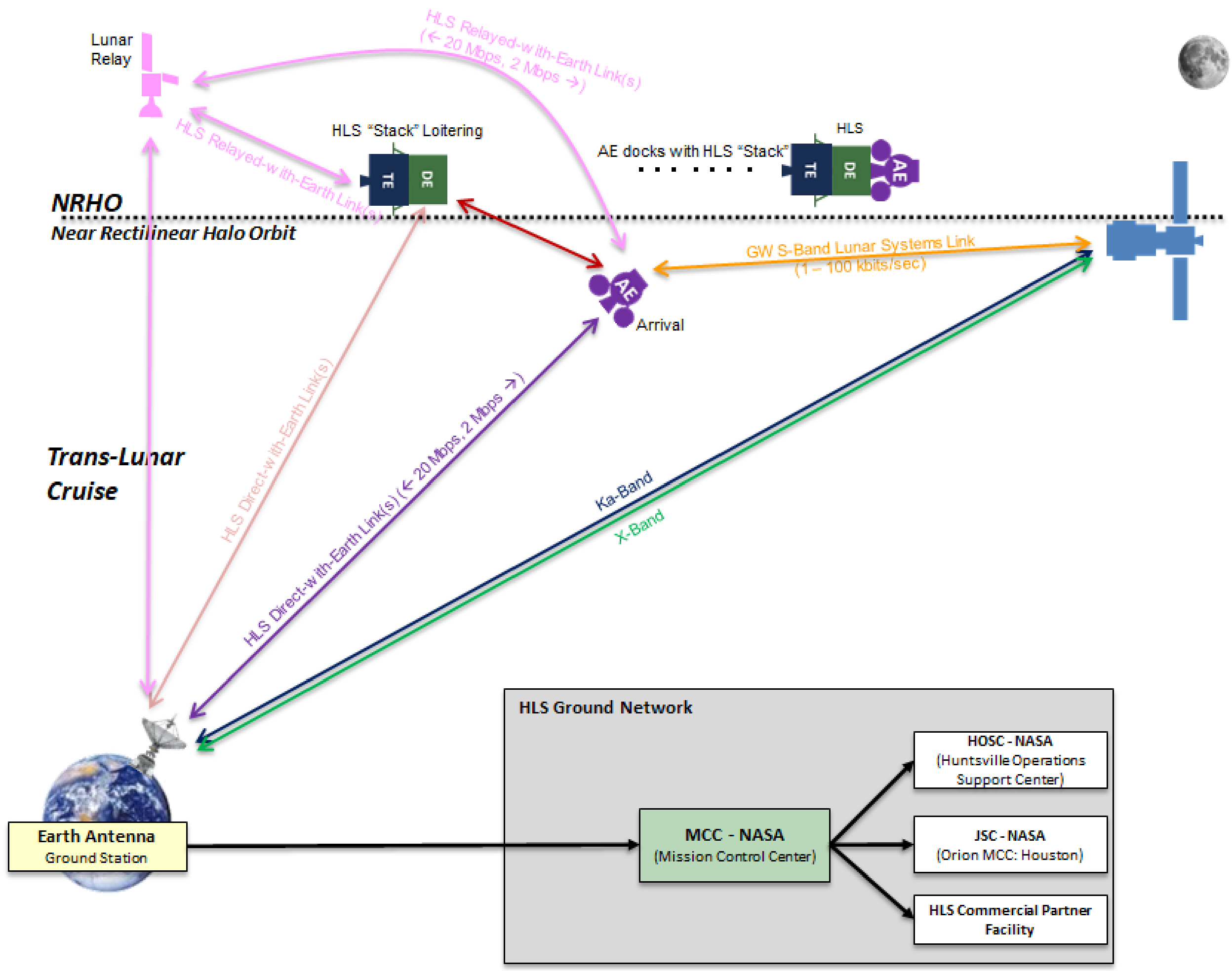


Figure 13-9 Ascent Element (AE) Arrival at NRHO, Docking with HLS Stack

13.1.5.5 HLS Docks with Gateway

The HLS Integrated Lander continues to maintain Direct-with-Earth Link(s) and/or Relayed-with-Earth link(s) for ranging and status. Upon entering Gateway Visiting Vehicle range (~400 km), the HLS Integrated Lander establishes simultaneous S-Band Visiting Vehicle link with Gateway for ranging, status and data transfer as shown in Figure 13-10. During RPOD operations, and when close enough, the HLS Integrated Lander establishes a Wi-Fi link to Gateway to support high-rate video and telemetry data transfer. Once docked, the HLS Integrated Lander can communicate through Gateway hardline Ethernet (as the primary means of data exchange with Gateway) and also possibly via Wi-Fi links.

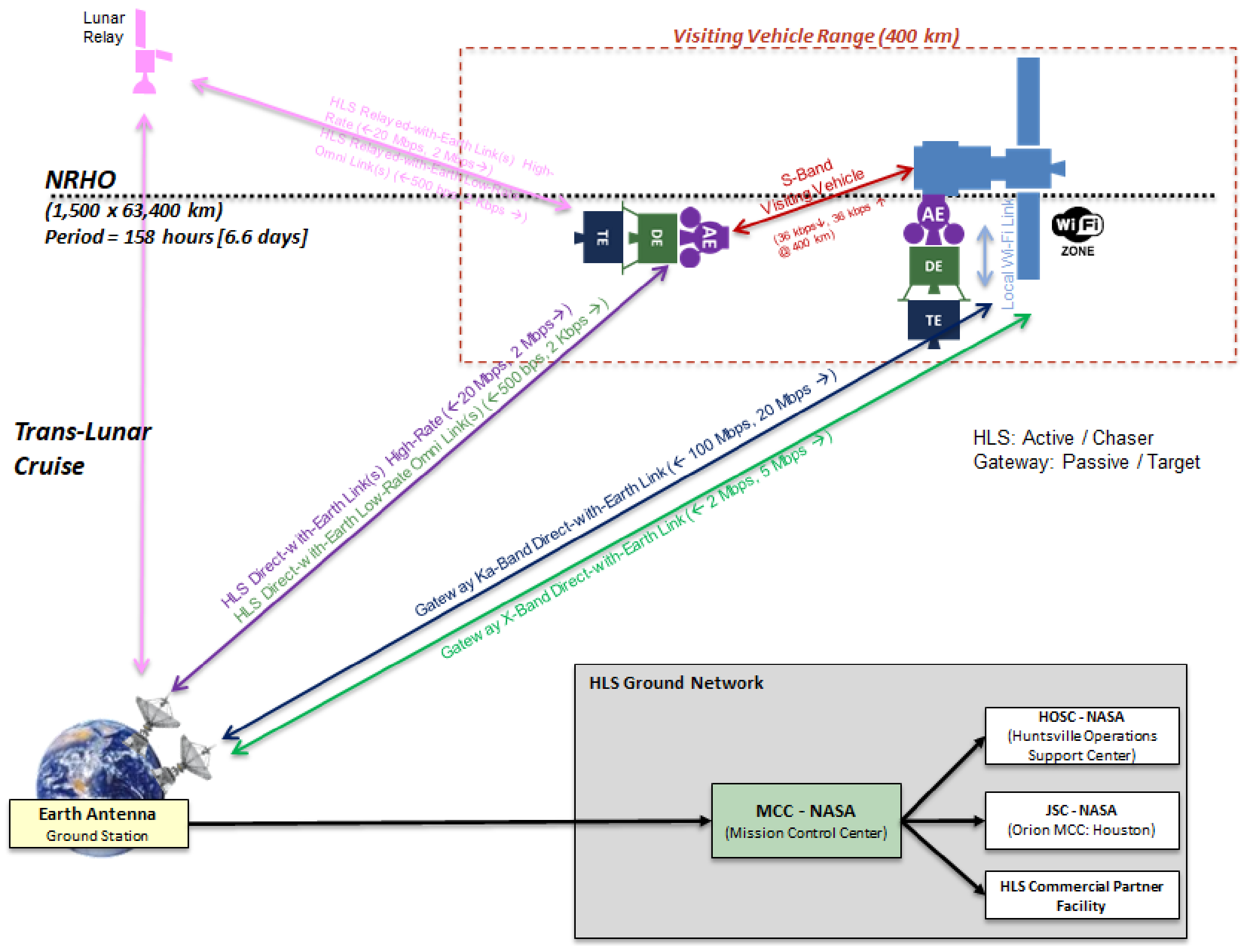


Figure 13-10 HLS Docks with Gateway

13.1.5.6 SLS/Orion Launch and Transit, arrival in NRHO

The HLS Integrated Lander remains docked to Gateway, awaiting the arrival of Orion, and communicates with Earth and/or Lunar Relay as necessary during this time period. The SLS launch, with a crew of four (4) aboard its Orion payload, will not proceed until the HLS Integrated Lander readiness has been established, including successful verification/check-out of the HLS Integrated Lander stack for lunar operations and successful completion of the Lunar Orbit Checkout Review (LOCR).

The Orion Launch Operations Mission Segment begins with the roll-out of SLS to KSC Pad 39B and ends after activation and checkout operations in a stable Low Earth Orbit. During the Outbound Operations Mission Segment, Orion completes a trans-lunar injection burn and arrives in NRHO as shown in Figure 13-11.

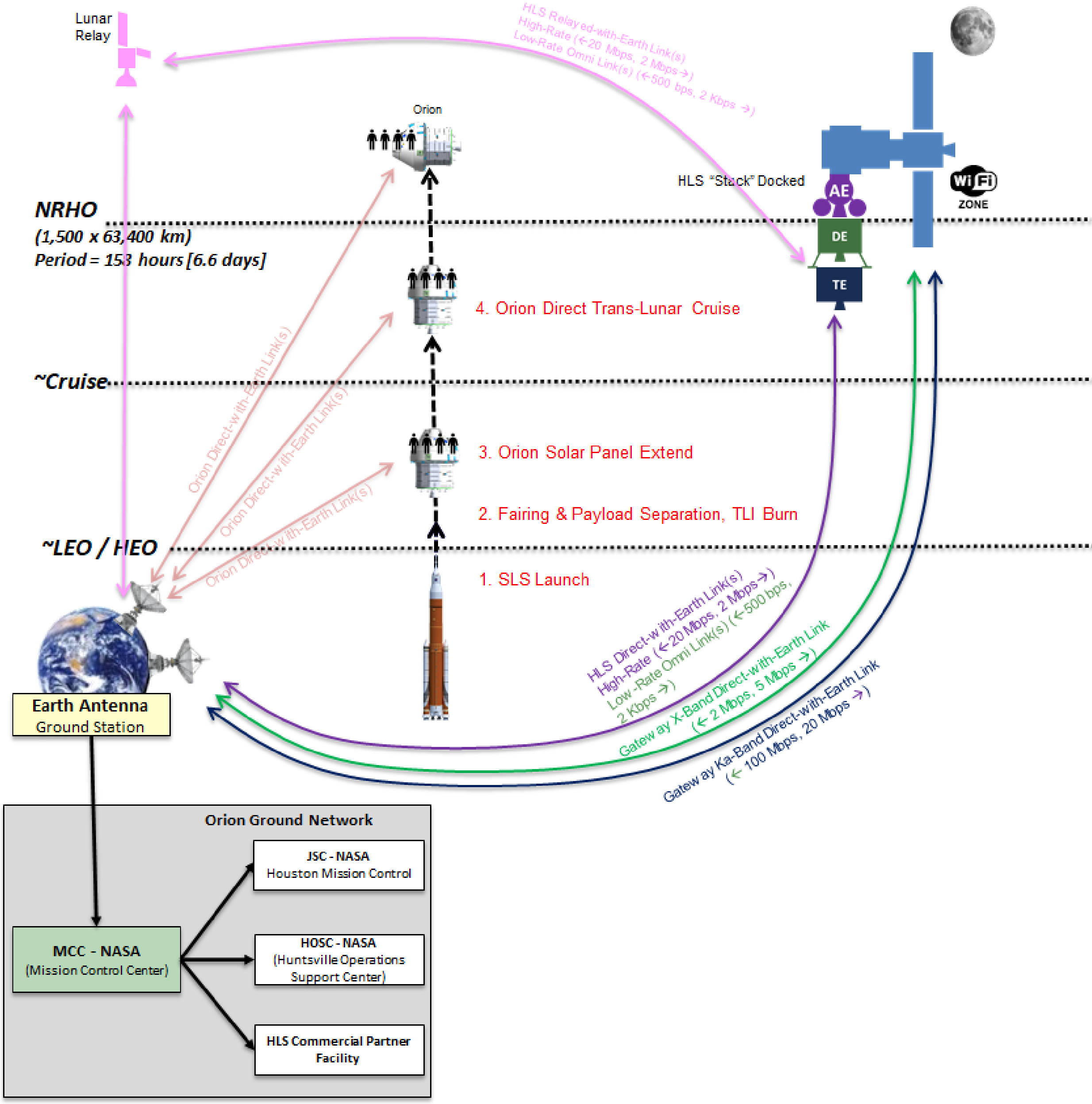


Figure 13-11 SLS/Orion Launch and Transit, arrival in NRHO

13.1.5.7 Crew Arrival, Transfer and Checkout

While docked, the HLS Integrated Lander can communicate through Gateway hardline Ethernet interface with Gateway, or via Wi-Fi with Gateway, and/or via an HLS Integrated Lander Direct-with-Earth and/or Relayed-with-Earth link(s) as shown in Figure 13-12 It is expected that the Gateway hardline interface will be primary during the docked phase. The Orion RPOD communications are outside the scope of this document, but the general idea is that Orion transports four (4) crew members up to Gateway, the crew then transfers into the Gateway Mini-

Habitation Module (MHM, also known as “HALO” [Habitation and Logistics Outpost]”), and from there, two (2) or four (4) crew members (DRM dependent) will enter the HLS Integrated Lander to prepare for lunar descent.

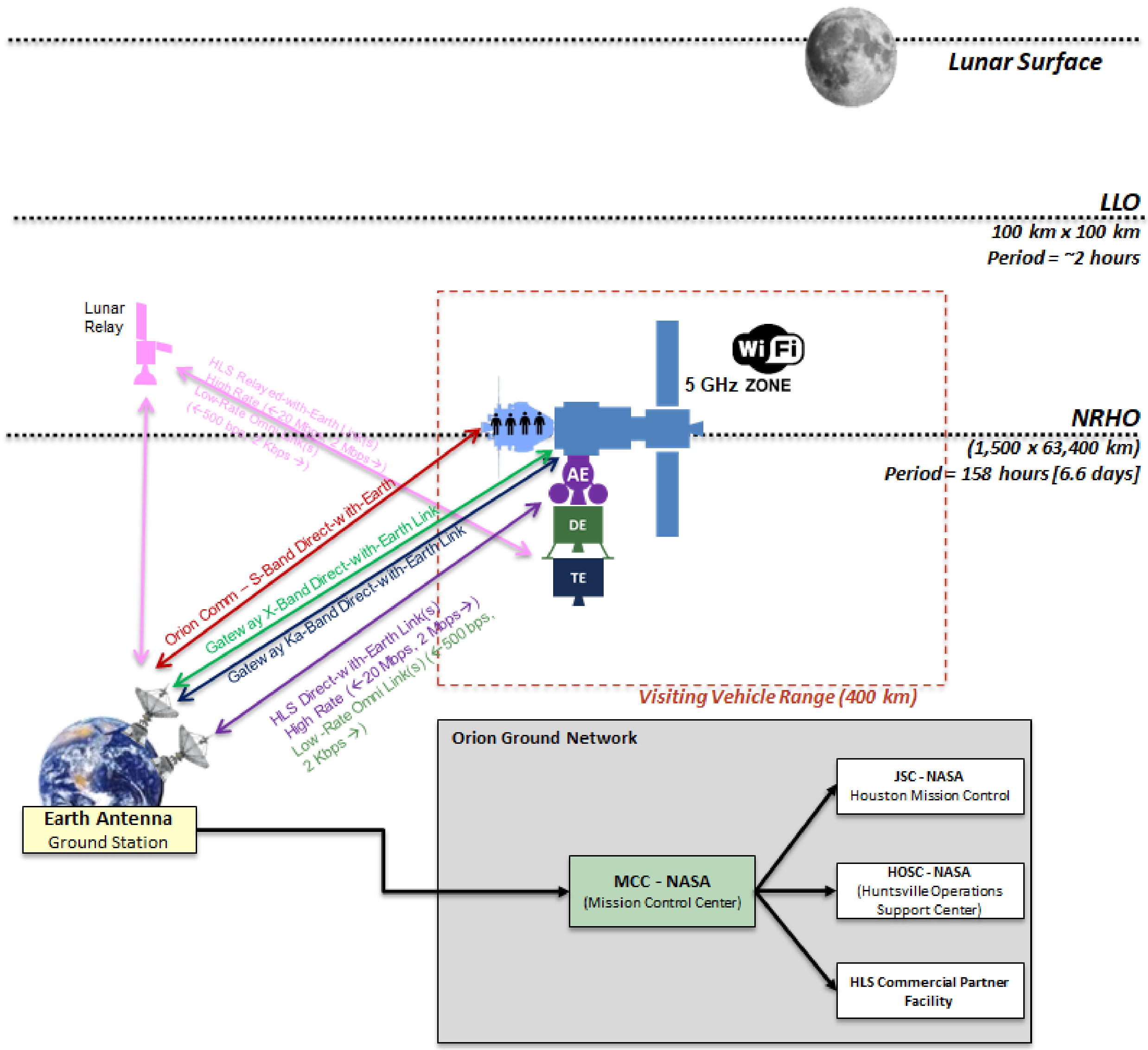


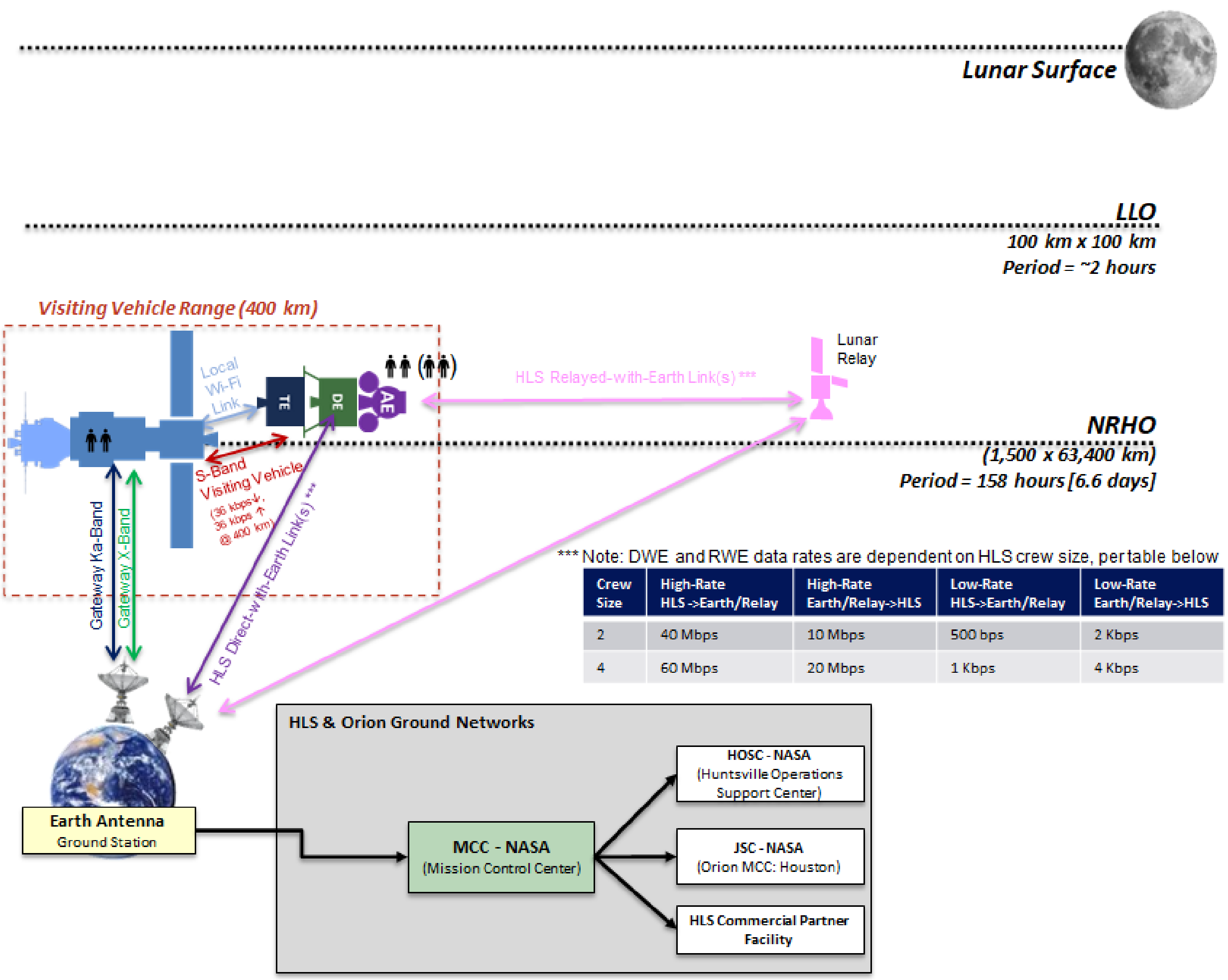
Figure 13-12 Crew Arrival, Transfer and Checkout

13.1.5.8 HLS Separation from Gateway – Departing for the Moon

Prior to separation from Gateway, the HLS Integrated Lander (Point A) establishes S-Band Visiting Vehicle link with Gateway (Point B) for ranging, crew communications and status as shown in Figure 13-13. As the HLS Integrated Lander physically undocks from Gateway, the hardline Ethernet connection is broken between the two vehicles. The HLS Integrated Lander also establishes simultaneous Direct-with-Earth link(s) and/or Relayed-with-Earth Link(s) for ranging, crew communications, health, and status as a dissimilar concurrent RF path.

While the HLS Integrated Lander remains within close proximity to Gateway, the Wi-Fi can still be used to exchange voice and data with Gateway (as available). Once outside Wi-Fi range, the HLS Integrated Lander will continue to maintain continuous RF communications links with both Gateway and Earth (i.e. direct and/or via relay). The HLS-Gateway VV link will drop to lowest 36 kbits/sec data rate to support 2-way voice communications out to a maximum distance of 400 km. Beyond 400 km, the HLS Integrated Lander will transition to the Gateway Lunar Systems link.

Real-time 2160p30 (UHD) video of the undocking and departure may be transmitted to Earth on the HLS Integrated Lander Direct-with-Earth Link(s) and/or Relayed-with-Earth Link(s) during this mission segment.



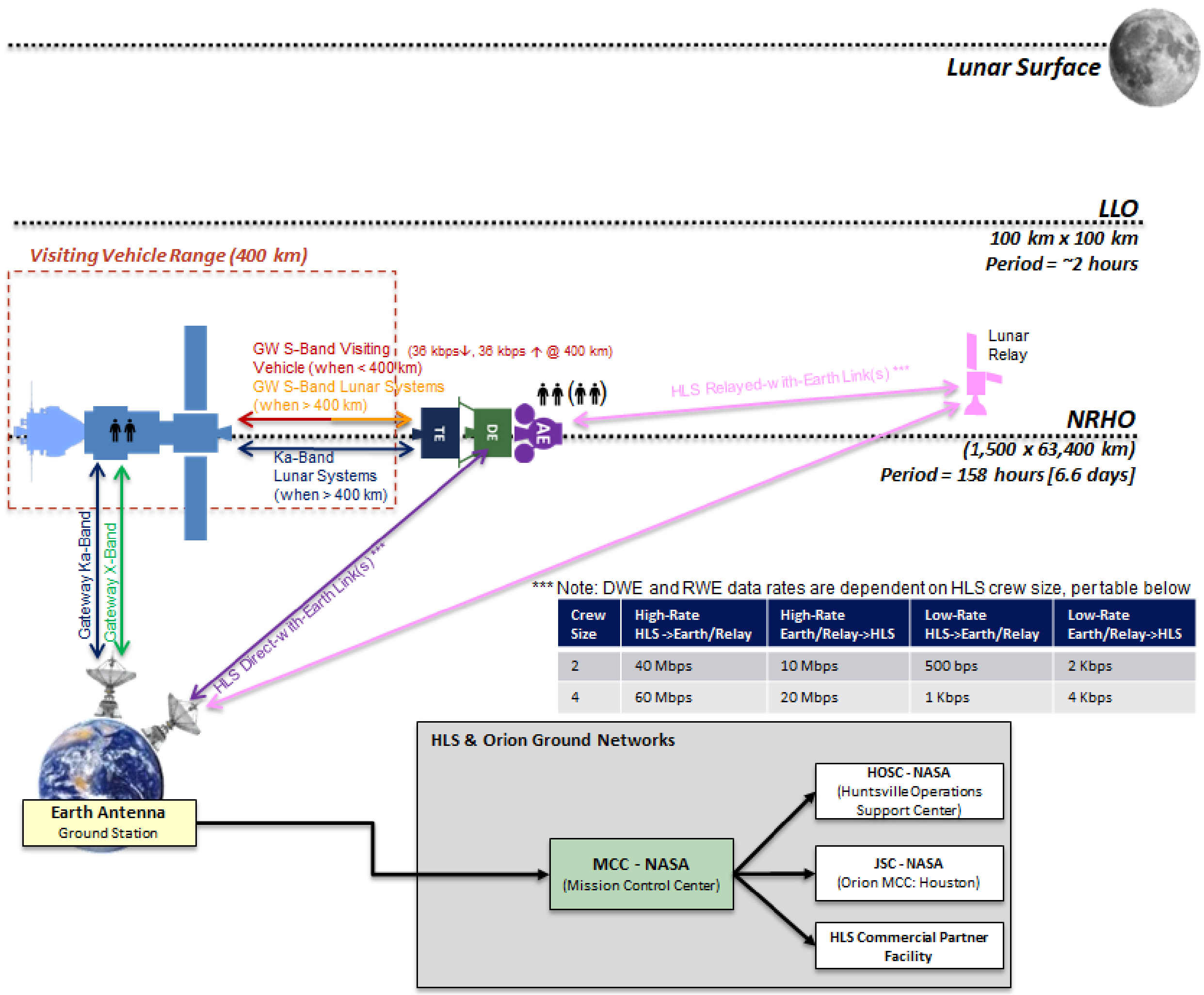
Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

Figure 13-13 HLS Separation from Gateway – Departing for the Moon

13.1.5.9 NRHO Departure – HLS Heading to the Moon

The HLS Integrated Lander (Point A) maintains S-Band Visiting Vehicle link with Gateway (Point B) for ranging, crew communications, status and tracking, while the HLS Integrated Lander simultaneously maintains Direct-with-Earth and/or Relayed-with-Earth Link(s) for ranging, crew communications, health, status and tracking.

Once beyond Visiting Vehicle range (~400 km), the HLS Integrated Lander maintains Direct-with-Earth and/or Relayed-with-Earth Link(s), and transitions from Gateway S-Band Visiting Vehicle Link to Gateway S-Band Lunar Systems link for ranging, crew communications ,and status as shown in Figure 13-14. The HLS Integrated Lander then has the option to establish an additional Ka-Band Lunar Systems link to Gateway for high-rate data transfer, if chosen.



*** Note: DWE and RWE data rates are dependent on HLS crew size, per table below

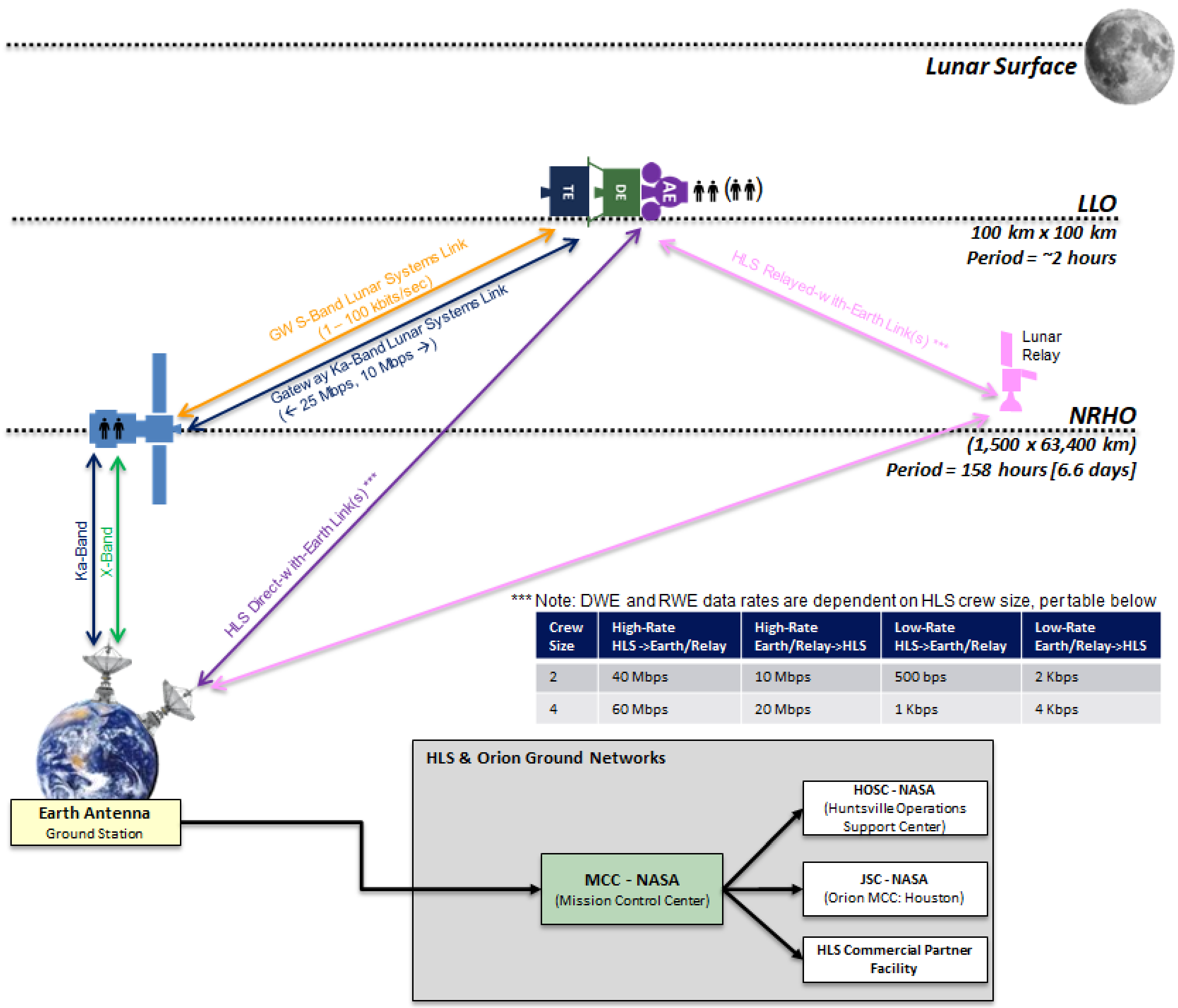
Crew Size	High-Rate HLS ->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

Figure 13-14 NRHO Departure – HLS Heading to the Moon

13.1.5.10 Low Lunar Orbit Arrival

The RF configuration is maintained when the HLS Integrated Lander separates from Gateway to depart for the lunar surface; however, during periods of expected signal loss with Gateway during phasing orbits in Low Lunar Orbit, the HLS Integrated Lander will rely on Direct-with-Earth and/or Relayed-with-Earth Link(s) for communications as shown in Figure 13-15. If there are periods where the Earth will not be in view of the HLS Integrated Lander, then the HLS Integrated Lander will rely upon Gateway and/or Lunar Relay as a communications relay with Earth; hence, the primary rationale for simultaneous and continuous RF links.

During this phase, the HLS Integrated Lander may want ~3 lunar orbits to collect navigation/tracking state information from the HLS-to-Earth Link to help with descent trajectory calculations/estimates.



*** Note: DWE and RWE data rates are dependent on HLS crew size, per table below

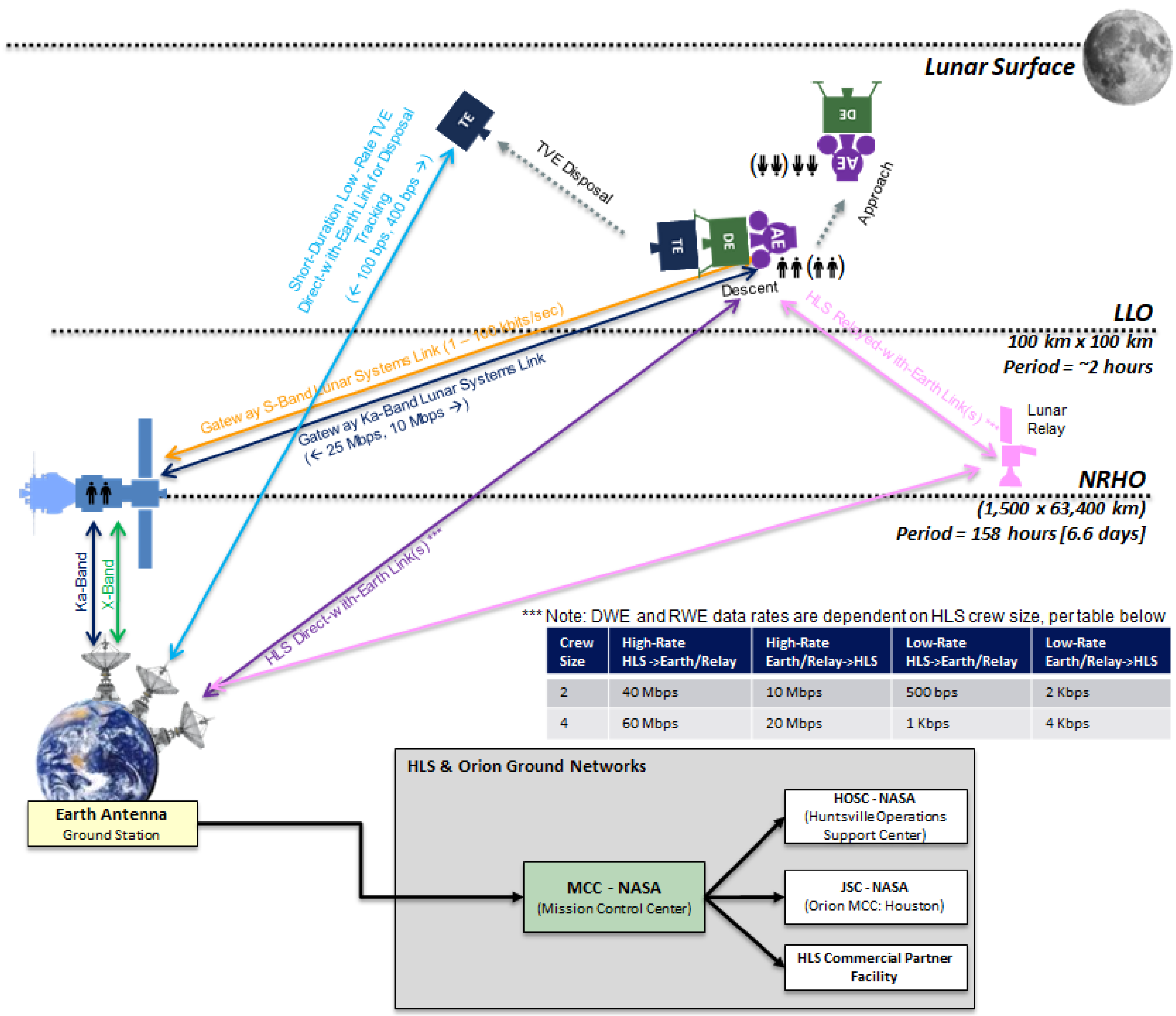
Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

Figure 13-15 Low Lunar Orbit Arrival – HLS Heading to the Moon

13.1.5.11 HLS Descent, TE Disposal, and Lunar Approach

During the HLS Integrated Lander descent, attitude perturbations may preclude the use of highly-directional (high-rate) links, such as Ka-Band, although efforts will be made to maintain the high-rate Direct-With-Earth and/or Relayed-with-Earth communications links as shown in Figure 13-16. At the same time, the HLS Integrated Lander will maintain a concurrent and continuous low-rate Direct-with-Earth and/or Relayed-with-Earth link, as a safety link, using 95% spherical antenna coverage, so that the link will not fail regardless of HLS Integrated Lander attitude perturbations during descent.

Separately, the HLS Integrated Lander Transfer Element will establish a low-rate (omnidirectional, spherical coverage) Direct-with-Earth link to facilitate tracking and low-rate data throughout TE disposal. After this link is established, the TE separates from the HLS Integrated Lander stack and de-orbits for disposal. The short-term TE link is maintained until contact with the TE is lost as it impacts the lunar surface. This additional Direct-with-Earth link may require additional ground station assets for communications and tracking.



Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

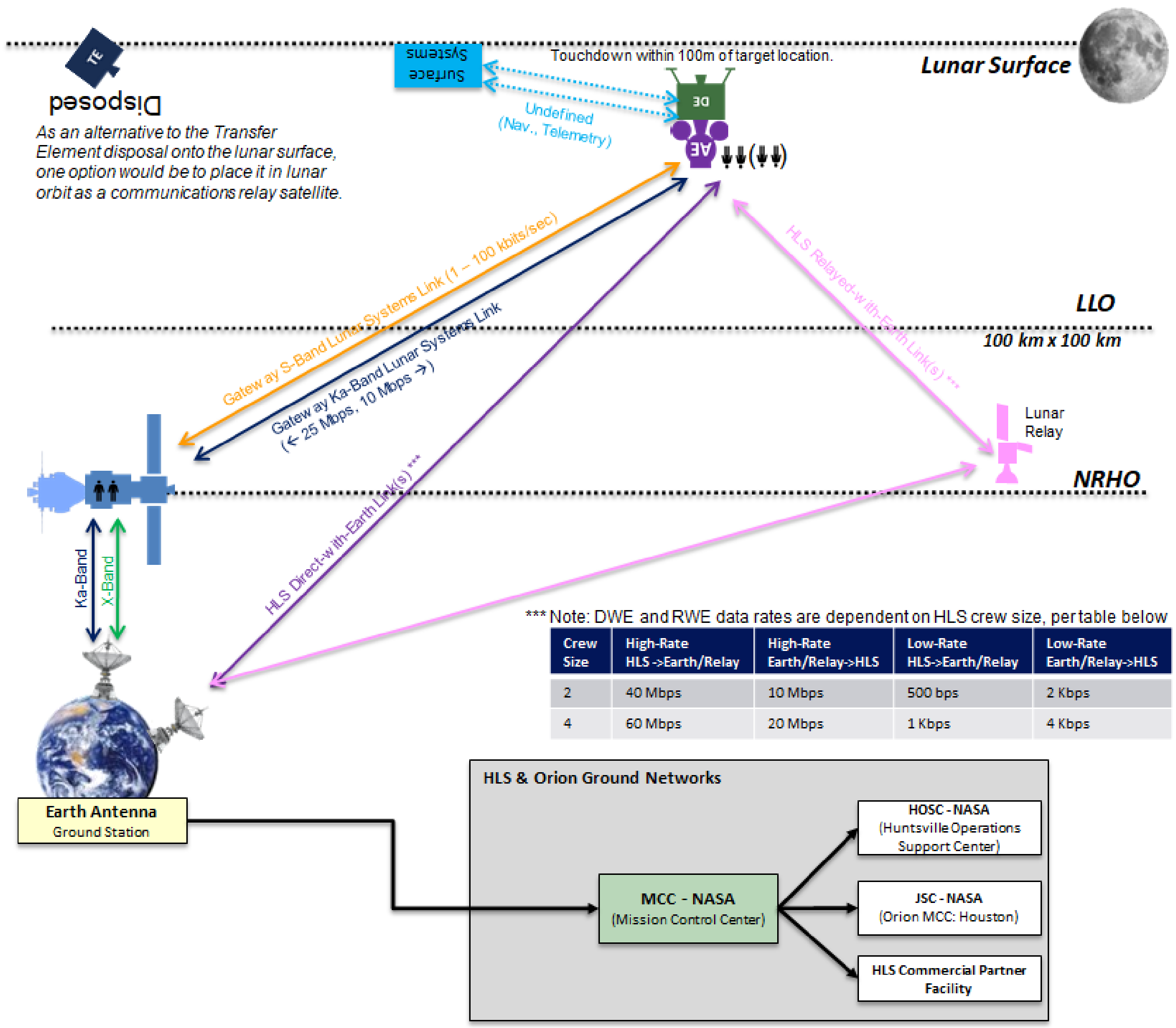
Figure 13-16 Descent, TE Disposal, and Lunar Approach

13.1.5.12 HLS Approach to Lunar Touchdown

The HLS Integrated Lander continues to maintain continuous spherical RF communications links with both Earth and Gateway during final descent as shown in Figure 13-17. The HLS Integrated Lander maintains a low-rate (most robust) Direct-With-Earth and/or Relayed-with-Earth omni-directional link, while attempting to maintain high-rate Direct-With-Earth and/or Relayed-with-Earth directional link, despite descent attitude perturbations.

Low-rate (spherical) RF communications links (i.e. to Gateway and Earth) should be generally continuous and uninterrupted during descent due to the nature of 95% spherical antenna coverage on the HLS Integrated Lander side. If high-rate (directional) RF communications links (most importantly for video or other high data rate applications) are lost, then attempts will be made to re-establish those directional links (with limited crew interaction) during the remainder of final approach/descent.

During this critical mission segment, larger Earth ground station assets—in addition to the 18m assets—may be needed. If so, the HLS Provider(s) should coordinate the request with SCaN to utilize (and prove compatibility with) the DSN 34m assets (scheduling of assets would be done by NASA or industry partner based on joint operations agreements).



Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

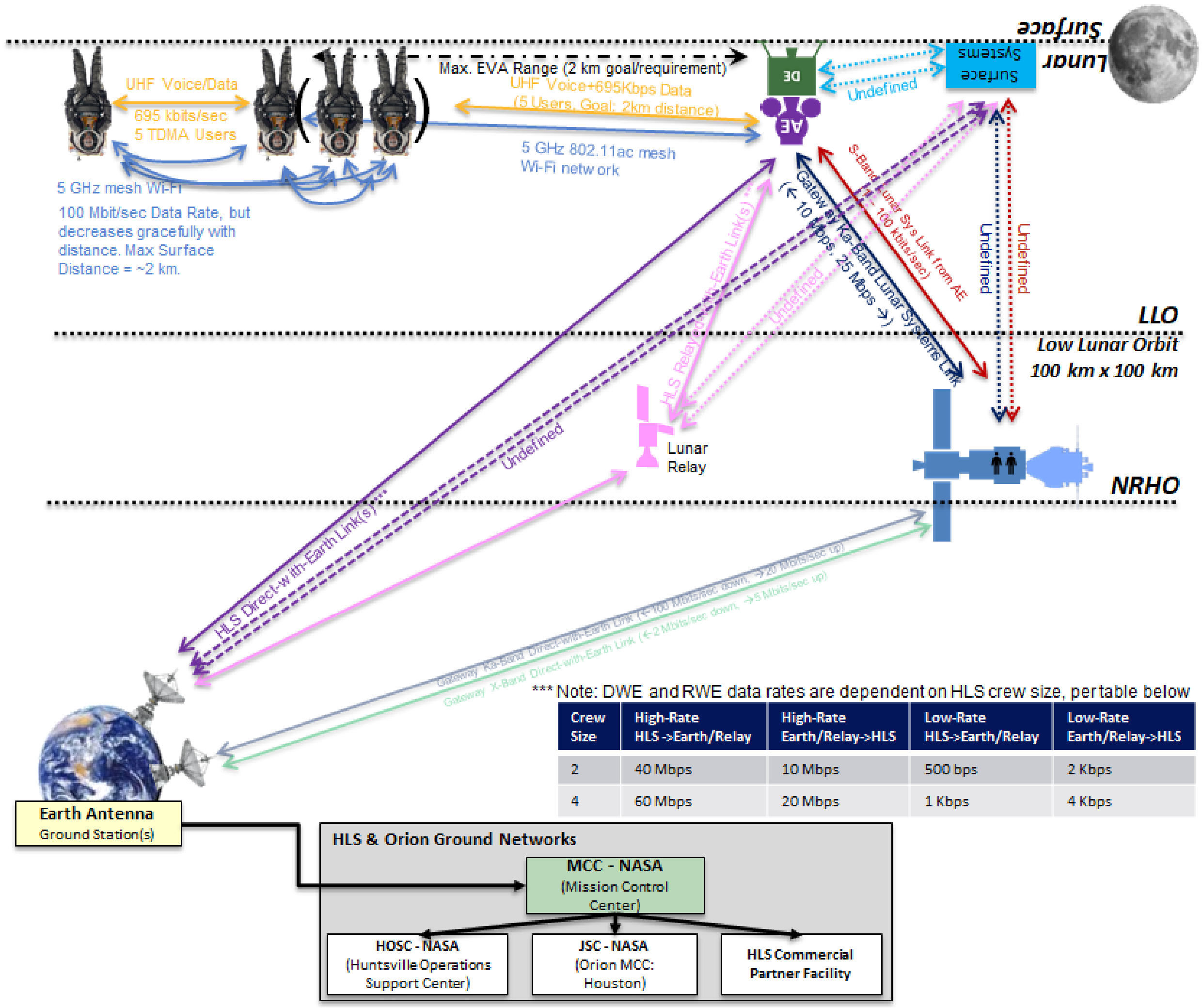
Figure 13-17 HLS Approach to Lunar Touchdown

13.1.5.13 HLS Surface Operations for Radio Frequency Communications

The HLS Integrated Lander maintains continuous communications with both Earth and/or Lunar Relay and Gateway while on the lunar surface as shown in Figure 13-18. Once the HLS Integrated Lander has landed (attitude stability), the HLS Integrated Lander can switch from Omni/Hemi antennas to directional antennas to achieve higher data rates for all links with both Gateway and Earth (or Earth via Lunar Relay). The RF link data rates should support at least two concurrent UHD real-Time video links, but preferably more.

Surface EVA astronauts will not have a direct communications link to Gateway, nor a direct link to Earth (either direct or via relay), as both would require directional antennas on the EVA side. Therefore, all EVA or LTV communications with Earth, Lunar Relay, and/or Gateway will go through the HLS Integrated Lander. During surface EVA activities, the HLS Integrated Lander uses a UHF EVA link to support astronaut voice and biomedical data links and uses external Wi-

Fi link to support proximity high-rate communications for less critical EVA related data (e.g. non-critical imagery, config files, helmet cameras) and peripheral devices such as video cameras or scientific instruments. The maximum range for EVAs is 2km for foot-traffic and 10 km for the Lunar Terrain Vehicle (LTV). NASA plans up to five EVAs over the ~6 Earth-Day maximum surface-stay duration.



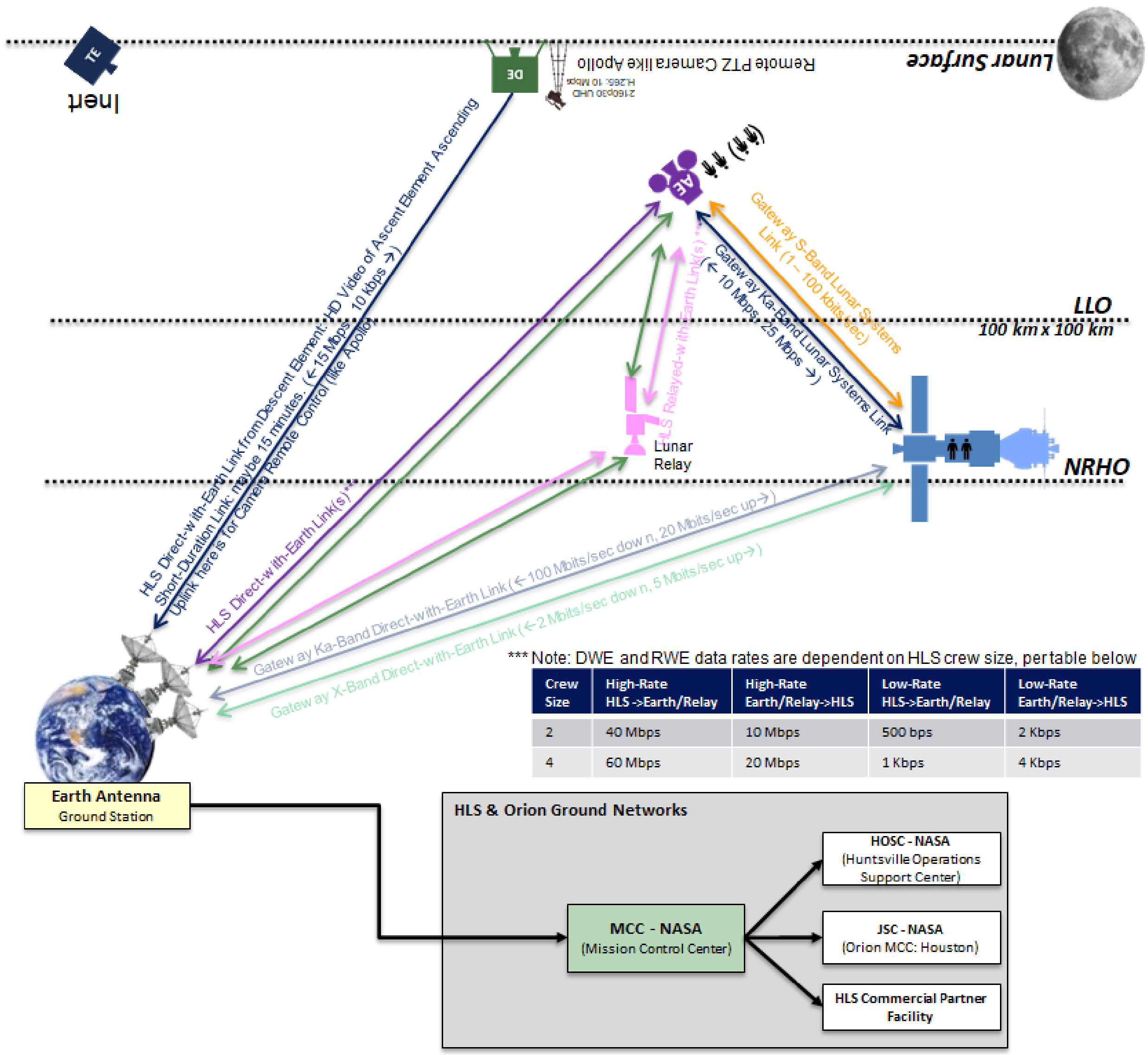
Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

Figure 13-18 HLS Surface Operations

13.1.5.14 HLS Ascent Element Lunar Liftoff

The AE maintains continuous Earth (direct and/or lunar relay) and Gateway links, as shown in Figure 13-19, but transitions to robust low-rate spherical links before liftoff to ensure that communications are not lost even in the event of HLS Integrated Lander attitude perturbations during ascent. The HLS Integrated Lander attempts to maintain the high-rate directional link with Earth and/or Lunar Relay during ascent.

During AE ascent, the DE (or a camera and transmitter connected to it or left separately behind by the EVA crew) should transmit live 2160p30 (UHD) video of AE departure/ascent via temporary high-rate Direct-with-Earth and/or Relayed-with-Earth link. This is similar to the Apollo missions. Mission Systems on Earth will have the capability to remotely command, or initiate a scripted command sequence prior to liftoff, the pan/tilt/zoom of the camera to better track the AE has it ascends away.



Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

Figure 13-19 HLS Ascent Element Lunar Liftoff

13.1.5.15 LLO Circularization to Departure Burn & Transfer Coast

The AE maintains continuous communications with both Earth and/or Lunar Relay and Gateway as shown in Figure 13-20. Once AE's attitude and directional antenna pointing is stable, the AE re-establishes the high-rate directional link with Earth for high-rate data transfer. During transfer coast, Gateway should always be in line-of-sight to the HLS Integrated Lander since the Gateway never hides behind the Moon during this segment. For any periods of expected signal loss with Gateway during phasing orbits in Low Lunar Orbit (LLO), AE will fall back to using only Direct-with-Earth and/or Relayed-with-Earth links.

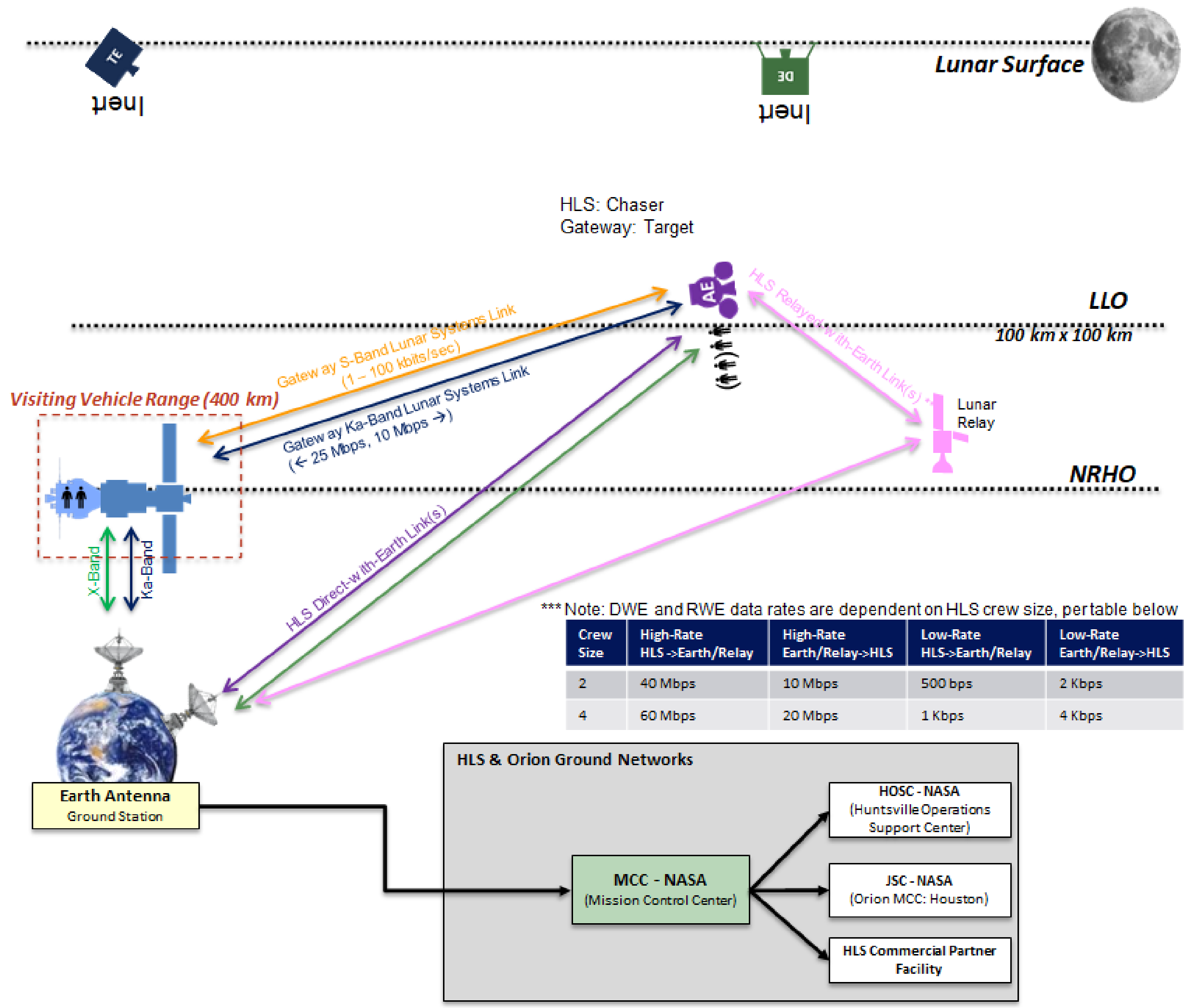
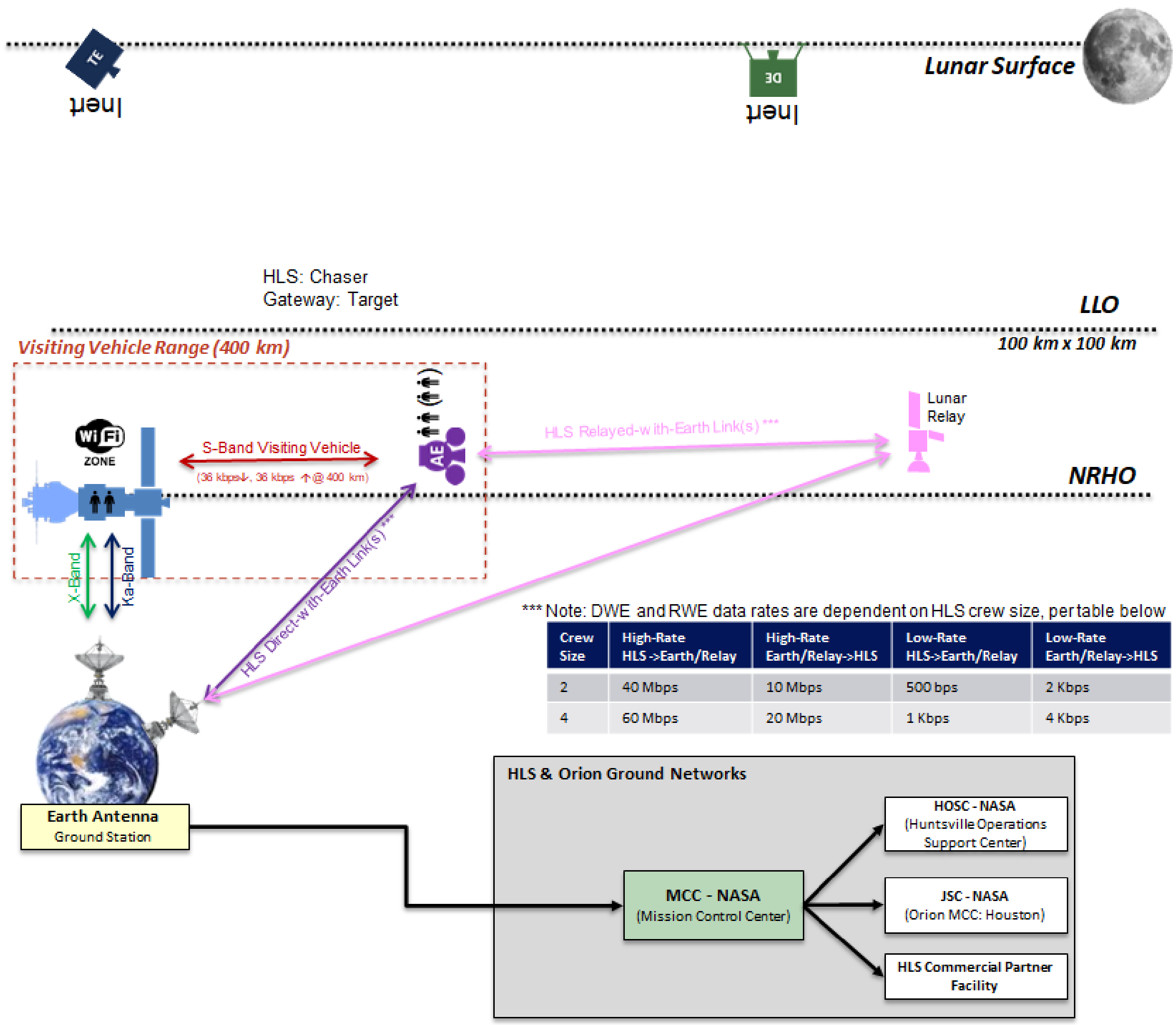


Figure 13-20 LLO Circularization to Departure Burn & Transfer Coast

13.1.5.16 NRHO Insertion Burn and RPOD

While maintaining RF Communication Link(s) with Earth and/or Earth via Lunar Relay, the AE transitions from the Gateway Lunar Systems S-Band Link to the Gateway Visiting Vehicle S-Band Link as it approaches within 400 km of Gateway as shown in Figure 13-21. In addition, the Gateway Ka-Band Lunar Systems link is also dropped. This configuration is maintained until docking with Gateway with the Wi-Fi link being available when in range (very close proximity).

Once docked, the AE uses hardline Ethernet communication (via docking port) as the primary means of data exchange with Gateway and Wi-Fi will remain available as a best-effort service to supplement the Ethernet connection. The two (or four) HLS Crew members (and any lunar cargo/samples gathered from the Moon) transfer back to Gateway/Orion and begin preparation for the return to earth (RTE).



Crew Size	High-Rate HLS->Earth/Relay	High-Rate Earth/Relay->HLS	Low-Rate HLS->Earth/Relay	Low-Rate Earth/Relay->HLS
2	40 Mbps	10 Mbps	500 bps	2 Kbps
4	60 Mbps	20 Mbps	1 Kbps	4 Kbps

Figure 13-21 NRHO Insertion Burn

13.1.5.17 Post-Mission Operation, Crew Return, and HLS Disposal

At the end of the crewed phase of the mission, the hatches between Gateway and the HLS Integrated Lander will be closed. The HLS Integrated Lander will remain docked until after Orion undocks and departs for Earth as shown in Figure 13-22. The HLS Integrated Lander may then undock for disposal or reuse preparations. Prior to separation from Gateway, the HLS Integrated

Lander (Point A) establishes S-Band Visiting Vehicle link with Gateway (Point B) for ranging and status. As the HLS Integrated Lander physically undocks from Gateway, the hardline Ethernet connection is broken between the two vehicles.

As element reuse is not a requirement for the sustaining phase of the HLS Provider(s) may choose to begin their uncrewed HLS Integrated Lander operations (refuel, orient to minimize boil off, etc.) or if they choose to dispose element/equipment/waste of the HLS Integrated Lander after the mission, these items will be disposed in locations that will pose no harm to or interfere with NASA lunar orbit missions or vehicles or assets of historical value and comply with applicable planetary protection regulations to ensure a safe disposal of the vehicle.

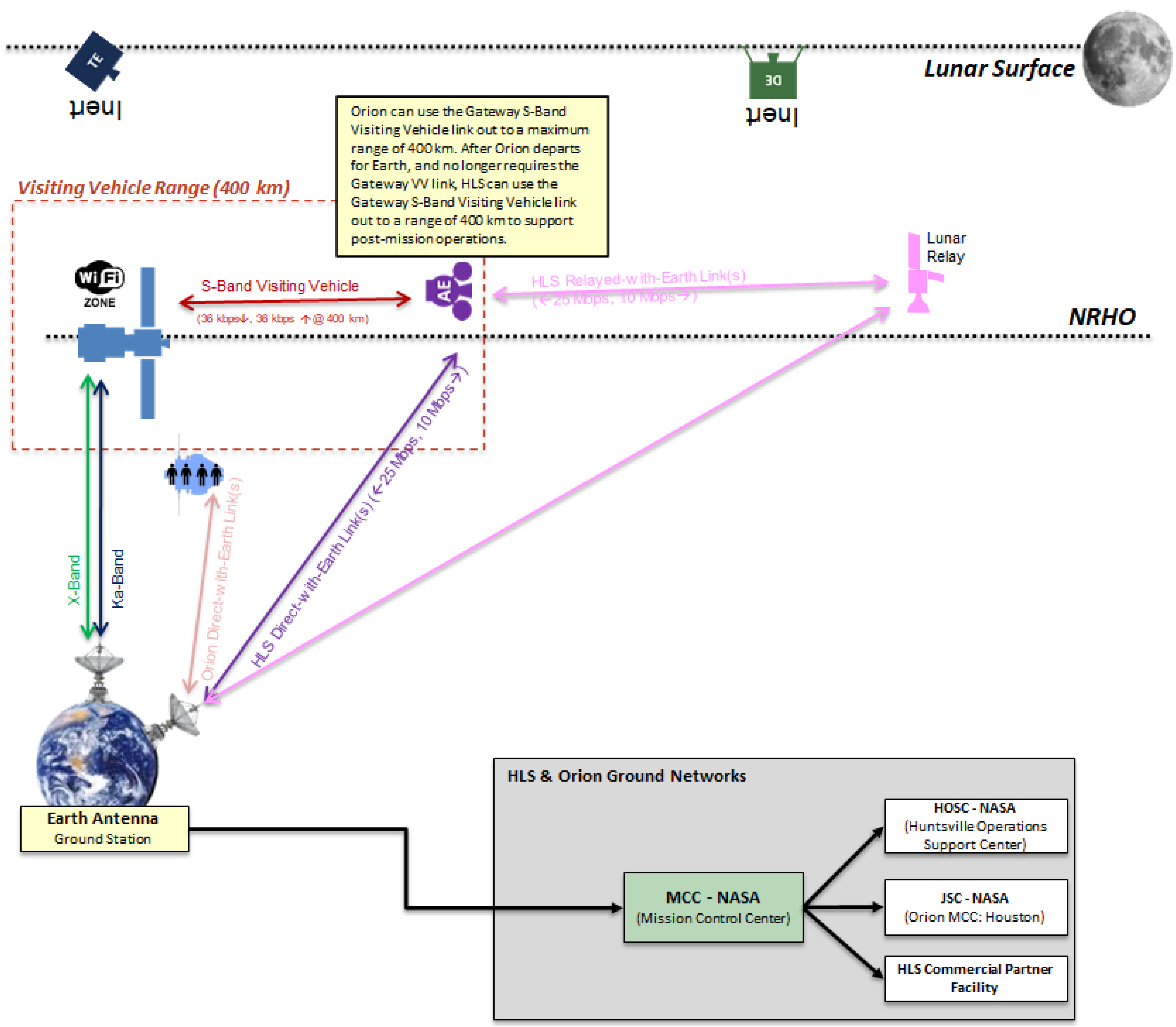


Figure 13-22 Post-Mission Operations, Crew Return, and HLS Disposal

13.1.6 Contingency Docking with Orion

13.1.6.1 HLS Contingency Docking with Orion

For an HLS Integrated Lander contingency docking with Orion, Orion will first have undocked with Gateway since the HLS Integrated Lander will not be able to dock with Gateway. The HLS Integrated Lander will hold position, including proper attitude to support Orion docking, in a safe range from Gateway. The HLS Integrated Lander and Orion each both continue to maintain their own Direct-with-Earth Link(s) and/or Relayed-with-Earth Link(s) for ranging and status as they prepare for contingency RPOD. Depending the on the range, and availability, either the Gateway VV (ranges < 400 km) or LS (ranges > 400 km) may also be utilized as an additional relay link. If within 400 km, the Gateway VV link can only support one user at a time.

When within 800 km, Orion (chase vehicle) initiates the S-Band Orion Proximity Link with the HLS Integrated Lander (in station-keeping mode) as shown in Figure 13-23. Orion, with its transponder operating in Point B (ground station) mode, calculates PN-code based range and range-rate data (800 km max limit on range calculation), and sends time-tagged tracking data to the HLS Integrated Lander, operating in Point A spacecraft mode, with a latency ≤ 3 seconds. Note that when ranging, the Orion to HLS Integrated Lander Forward Proximity link will be low rate—maximum of 72 kbits/sec, at best. However, the converse is not true. The HLS Integrated Lander to Orion Return Proximity link can go up to 6 Mbits/sec (at best), when in very close range. Once hard docking is confirmed, the HLS Integrated Lander will pressurize the docking vestibule, the HLS crew will safe the HLS Integrated Lander, transfer to Orion including lunar samples and any needed consumables, and then prepare for undocking.

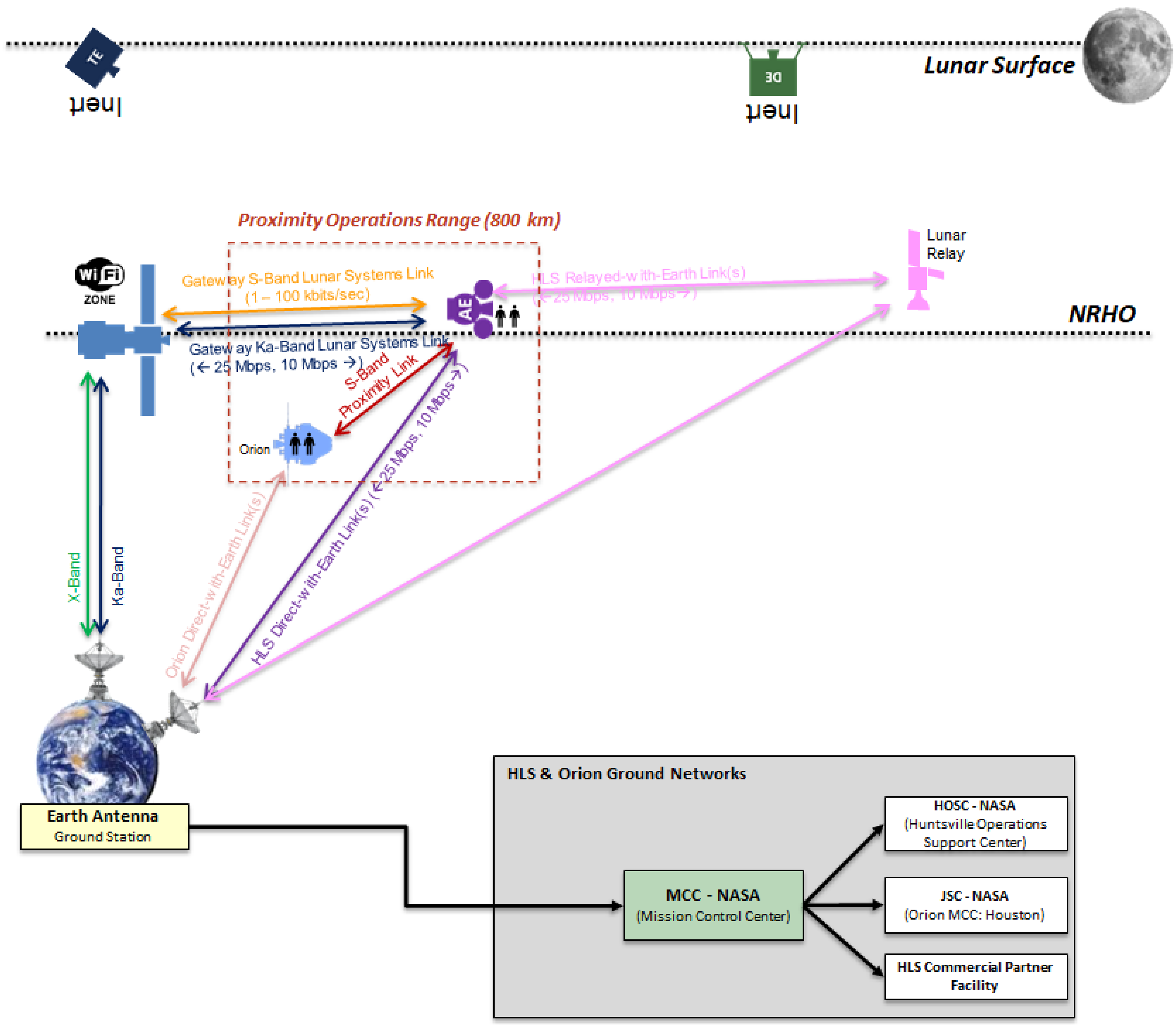


Figure 13-23 Contingency Docking with Orion (MPCV) – RPOD

13.1.6.2 HLS Contingency Docking – Post-Mission Mission Operations

Prior to separation from the HLS Integrated Lander, Orion (Point B) establishes the S-Band HLS/Orion Proximity link with the HLS Integrated Lander (Point A) for ranging, crew communications, and status. As the HLS Integrated Lander physically undocks from Orion, the hardline Ethernet connection is broken between the two vehicles. The HLS Integrated Lander maintains simultaneous Direct-with-Earth and/or Relayed-with-Earth Link(s) for ranging, crew communications, health, and status (i.e. two concurrent HLS Integrated Lander links) as shown in Figure 13-24. If Gateway is within range, the Gateway LS may be utilized as an additional relay link. The S-Band Orion Proximity Link may be used up a maximum separation distance of 800 km.

After Orion undocks and departs for Earth, the HLS Integrated Lander may then prepare for disposal or reuse. As element reuse is not a requirement for the sustaining phase of the HLS

Integrated Lander, Provider(s) may choose to begin their uncrewed HLS Integrated Lander operations (refuel, orient to minimize boil off, etc.) or if they choose to dispose element/equipment/waste of the HLS Integrated Lander after the mission, these items will be disposed in locations that will pose no harm to or interfere with NASA lunar orbit missions or vehicles or assets of historical value and comply with applicable planetary protection regulations to ensure a safe disposal of the vehicle.

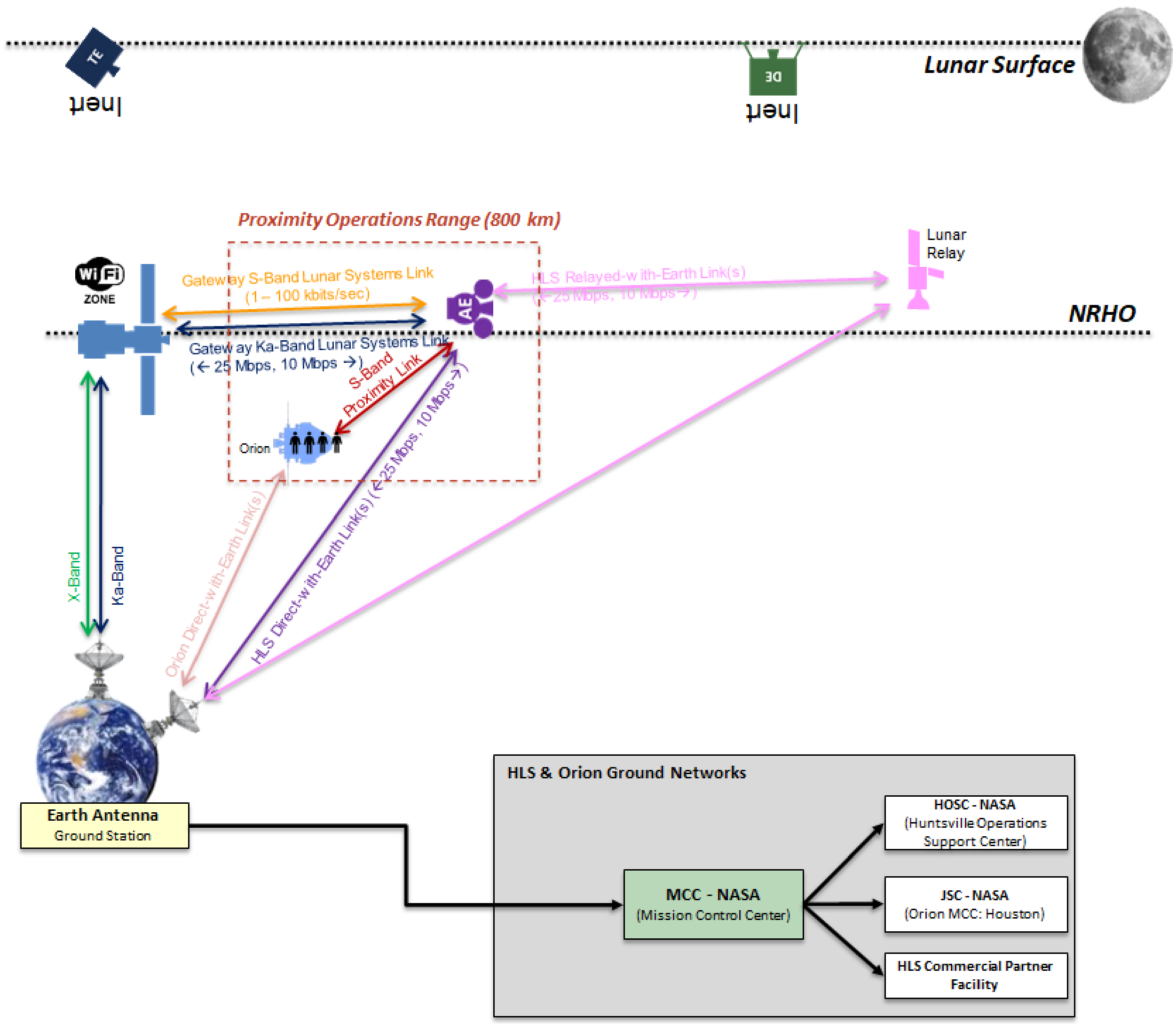


Figure 13-24 Contingency Docking with Orion (MPCV) – Undocking and Crew Return

APPENDIX A
ACRONYMS AND ABBREVIATIONS
AND GLOSSARY OF TERMS

A1.0 ACRONYMS AND ABBREVIATIONS

Table A1-1 Acronyms And Abbreviations

AADA	Active-Active Docking Adapter
AE	Ascent Element
AES	Advanced Exploration System, or Advanced Encryption Standard (I.e. 256-bit)
BEO	Beyond Earth Orbit
BPSK	Binary Phase Shift Keying
CCSDS	Consultative Committee for Space Data Systems
C^3I	Command, Control, Communications, and Intelligence
CLV	Commercial Launch Vehicle
CM	Crew Module
ConOps	Concept of Operations
CUI	Controlled Unclassified Information
CR	Change Request
CSV	Crew Staging Vehicle
DTN	Delay Tolerant Networking
dB	Decibel
DE	Descent Element
DRM	Design Reference Mission
DSN	Deep Space Network
DWE	Direct-with-Earth (Sometimes also referred to as DTE, Direct To Earth)
EVA	Extravehicular Activity
FCC	Federal Communications Commission
FEC	Forward Error Correction
FHD	Full High Definition
FOV	Field of View
GCM	Galois/Counter Mode
GP	Gateway Program
GFP	Government Furnished Property
GHz	Gigahertz
HALO	Habitation and Logistic Outpost
HEO	Human Exploration and Operations
HLS	Human Landing System
ICSIS	International Communications System Interoperability Standard

Table A1-1 Acronyms And Abbreviations

IRCD	Interface Requirements Document
IRD	Interface Requirements Document
ITU	International Telecommunication Union
IVA	Intravehicular Activity
LAS	Launch Abort System
LV	Launch Vehicle
LEGS	Lunar Exploration Ground Sites
LEO	Low Earth Orbit
LLO	Low Lunar Orbit
LOCR	Lunar Orbit Checkout Review
LS	Lunar System
LSO	Lunar Staging Orbit
LSS	Lunar Surface Sortie
LTE	Long Term Evolution
LTV	Lunar Terrain Vehicle
MCC	Mission Control Center
MPCV	Multi-Purpose Crew Vehicle
Mbps	Mega bits per second
Msps	Mega Symbols per second
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NDS	NASA Docking System
NSN	Near Space Network
NRHO	Near-rectilinear Halo Orbit
OPR	Office of Primary Responsibility
PAA	Phased Array Antennas
PPE	Power Propulsion Element
PSK	Phase Shift Keying
PM	Phase Modulation
PNT	Positioning, Navigation, and Timing
PR	Pressurized Rover
PN	Pseudo-Random Noise
PCM	Pulse Code Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RR	Radio Regulations
RWE	Relayed-with-Earth
RPOD	Rendezvous Proximity Operations and Docking

Table A1-1 Acronyms And Abbreviations

RPODU	Rendezvous Proximity Operations and Docking and Undocking
RTE	Return to Earth
SZM	Shielded Zone of the Moon
SCaN	Space Communication and Navigation
SFCG	Space Frequency Coordination Group
SN	Space Network
SPD	Space Policy Directive
SRS	Space Research Service
SM	Service Module
TVA	Threat & Vulnerability Assessment
TBD	To Be Determined
TBR	To Be Resolved
TCM	Trajectory Control Maneuver
TDRS	Tracking and Data Relay Satellites
TT&C	Tracking, Telemetry, and Command
TE	Transfer Element
UHD	Ultra-High Definition
UHF	Ultra-High Frequency
VoIP	Voice over Internet Protocol
VV	Visiting Vehicle
xEVA	Exploration Extra-Vehicular Activities

A2.0 GLOSSARY OF TERMS

Table A2-1 Glossary Of Terms (Future Work)

Term	Description
Abort	The forced early return of the crew to the crewed staging vehicle when failures or the existence of uncontrolled catastrophic hazards prevent continuation of the mission profile and a return to the crewed staging vehicle is required for crew survival.
Automated	The capability of a vehicle system or subsystem to perform a task, function, operation or process.
Autonomous	The capability of the Integrated Lander (including crew when present) to perform operations independent from a specified external system or authority structure (e.g., any ground-based systems, mission control, or a crewed staging vehicle).

Table A2-1 Glossary Of Terms (Future Work)

Term	Description
Crew Staging Vehicle	The vehicle that serves as the crew transfer conduit to and from the HLS integrated lander; Gateway will fill this role for sustaining missions. Orion will transport the crew to NRHO, then enables transfer of crew between Orion and Gateway. Gateway then enables transfer of crew between Gateway and the HLS integrated lander.
Direct with Earth (DWE) Link	An RF link with geometric line-of-sight capability with Earth. Can be uni- or bi-directional (should always be specified). Direct to Earth (DTE) is sometimes used interchangeably.
Excursion Mission	A mission type that includes delivering four crew from NRHO to the lunar surface and returning to NRHO, which does involve pre-emplaced surface assets for achieving mission objectives. Excursion Missions include a generally longer surface duration than Surface Sortie Missions, e.g., approximately 33 days.
Extravehicular Activity/EVA	An EVA is defined as a single event, involving suited crew, starting with switching the suit from external power (or beginning of depressurization for an umbilical EVA) and ends when repressurization has been initiated. Depressurization and repressurization do not have to occur in the same vehicle. For safety purposes, EVAs are always performed with two or more suited crewmembers.
Integrated Lander	Any combination of Integrated Lander Elements, including potentially a single Integrated Lander Element, that is used for crew transportation, and is integrated at any time crew are onboard. Any docking adapter utilized by the contractor during the performance of this contract is considered a part of the Integrated Lander.
Integrated Lander Element	A spacecraft capable of operating independently of other spacecraft and that is also either: (1) used to transport crew during the performance of crewed missions; or (2) connected at any time to other spacecraft while the other spacecraft is transporting crew during the performance of this contract. Examples of an Integrated Lander Element may include, but are not limited to, Ascent, Descent, or Transfer elements.
Lunar Surface Mission	A general reference that includes both Sorties and Extended Surface Stays. The term refers to any mission in which landing on the lunar surface is the nominal objective.

Table A2-1 Glossary Of Terms (Future Work)

Term	Description
Mission	A sequence of activities or operations that are required to achieve one (or more) Agency goal(s). A mission can be broken down into "Mission Phases" (which group the sequence of activities or operations based on major mission milestones) for the purposes of communicating aspects of the operations, timeline, or performance. Each mission or mission phase can have its own set of elements and modules that are used to pursue the Agency goal(s). The duration of a mission or mission phase is defined by the activities or operations within it; additionally, the duration of a mission phase can be indirectly defined by the adjacent mission phases.
Mission Phase	A distinct period or stage in a series of events that comprise a Design Reference Mission (DRM). *Disambiguation note: The terms mission segment and mission phase co-exist within the Program and are sometimes used interchangeably by the Program itself or external organizations. The HLS Program has opted to not settle upon one term or another because the linguistic differences were deemed insignificant and not meaningful regarding the Program's overall technical context and its dialog with external organizations.*
Mission Segment	Each of the parts into which a DRM or one of its mission phases is or may be divided. The role title "Mission Segment Lead" has been formally adopted by the Program, as described within HLS-PLAN-016 Technical Management Plan §5.2.3 Mission Segment Leads and Discipline Lead. *Disambiguation note: The terms mission segment and mission phase co-exist within the Program and are sometimes used interchangeably by the Program itself or external organizations. The HLS Program has opted to not settle upon one term or another because the linguistic differences were deemed insignificant and not meaningful regarding the Program's overall technical context and its dialog with external organizations.*

Table A2-1 Glossary Of Terms (Future Work)

Term	Description
Mission Systems	The end-to-end terrestrial based hardware and software infrastructure, whether owned or operated by NASA or the contractor, supporting mission operations from the point of Radio Frequency (RF) receipt/transmit at RF communications ground sites, through associated data processing and distribution infrastructure, transport networks, mission control center systems and facilities, interfaces between operations facilities, to the end user display/control systems and support infrastructure. Mission Systems include all associated hardware and software infrastructure supporting crew and flight controller training for operations, including but not limited to simulations, networks, mockups, and interfaces to support infrastructure.
Non-Polar	Term meaning that all latitudes are available, but not necessarily that all latitude/longitude combinations are available. Some areas at low latitudes and longitudes near zero degrees may not be reachable.
Primary	Modifier term that is applied to DRM-H-001 and DRM-H-002 in HLS-CONOP-006. Primary DRMs describe the current understanding of mission types to be used in the sustained phase of lunar exploration.
Surface Sortie Mission	A mission type that includes delivering two crew members from NRHO to the lunar surface and returning to NRHO, which does not rely on pre-emplaced surface assets for achieving mission objectives. Surface Sortie Missions include a generally short surface duration, e.g., six days or less.
Variant	Modifier term that is applied to DRM-H-001 and DRM-H-002 in HLS-CONOP-006. Variant DRMs are a representation of how the capability established by the primary DRM may be used in different operational contexts and external environments than would be seen during a mission represented by the primary DRM.

APPENDIX B
OPEN WORK

B1.0 TO BE SPECIFIED (HEADING-APPX STYLE - ALL CAPS AND BOLD)

The table To Be Specified Items lists the specific To Be Specified (TBS) items in the document that are not yet known, is used when something is to be decided or confirmed at some point in the future and in the place of TBD, TBR, TBC, TBX. The TBS is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBS item is numbered based on the document number (i.e., **<TBS-xxxx-00x-001>** is the first undetermined item assigned in the document). As each TBS is resolved, the updated text is inserted in each place that the TBS appears in the document and the item is removed from this table. As new TBS items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBSs will not be renumbered.

Table B1-1 To Be Specified Items

TBD	Section	Description

B2.0 FORWARD WORK

The table Forward Work lists the specific Forward Work (FWD) issues in the document that are not yet known, used for issues/items that are not yet completed, and is also used to capture work that will mature/evolve through further analysis. Include any CR comments that were dispositioned as Forward Work. The FWD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The FWD issue is numbered based on the document number (i.e., **<FWD-xxxx-00x-001>** is the first forward work assigned in the document). As each FWD is resolved, the updated text is inserted in each place that the FWD appears in the document and the issue is removed from this table. As new FWD issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original FWDs will not be renumbered.

Table B2-1 Forward Work Items (Placeholder)

TBR	Section	Description

APPENDIX C
RF COMM REFERENCE INFORMATION

RESERVED