Optical communications operations concept for the Artemis II crewed mission to the Moon

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ABSTRACT

NASA's Artemis II mission includes an optical communication payload, affectionately known on board as "OpCom," which is part of NASA's Orion Artemis II Optical Communications (O2O) demonstration. We describe the OpCom system architecture and operations concept.

Keywords: free-space optical communication, laser communication, lasercom, human space exploration, space operations

1. INTRODUCTION

Artemis II is the second in a series of Artemis missions designed to explore the Moon and beyond and will eventually land astronauts on Mars [1]. Artemis II will launch the Orion spacecraft in 2024 and take 4 astronauts around the Moon. Since the average human's desire for "bandwidth" has increased substantially since the Apollo program, the Orion spacecraft has been designed to include a free-space optical communication terminal capable of both transmitting and receiving high rate laser communication (lasercom) signals [2]. The lasercom portion of Artemis II is called the Orion Artemis II Optical Communications (O2O) demonstration, but the astronauts will call it OpCom. OpCom will provide a physical layer link creating a transparent Ethernet bridge over which the vehicle can transmit and receive files, make real-time video calls, and stream real-time camera images and video. OpCom nominally provides an 80 Mbps (with capability up to 260 Mbps) downlink and a 20 Mbps uplink. Orion subsystems are expected to generate ~ 300 GB of data on orbit during the 10-day mission as shown in Figure 1. Using S-Band alone, Orion is limited to ~ 7 GB of data downlink per day. With just 1 hour per day of OpCom's lasercom link, Orion can downlink 36 GB per day, a 6-fold increase per day [2].

NASA's interest in lasercom began with the very successful Lunar Laser Communication Demonstration (LLCD) in 2013 which flew on the Moon-orbiting Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite [3]. LLCD demonstrated a 622 Mbps optical downlink and a 20 Mbps optical uplink, both error free, over a variety of different conditions. The LLCD payload was designed, built, and operated by MIT Lincoln Laboratory (MITLL) and the payload design and ops concept was subsequently used by NASA to fly on the STPSat-6 as part of the Laser Communication Relay Demonstration (LCRD) [4]. A subsequent development effort at MITLL resulted in a novel Modular, Agile, Scalable Optical Terminal (MAScOT) [5]. This MAScOT architecture is employed in both the Integrated LCRD Low-Earth-Orbit (LEO) Modem and Amplifier Terminal (ILLUMA-T) [6], a follow-on program to LCRD which provides a high bandwidth lasercom link to/from the International Space Station [7], and the OpCom (O2O Mission) on Artemis II discussed in this paper.

The lasercom system on Artemis II has a novel operations concept when compared with prior systems such as LLCD, LCRD and ILLUMA-T. For those systems, the payload was/is operated by the agency that developed the payload, e.g. MITLL / NASA Goddard Space Flight Center (GSFC). However, since Artemis II is a crewed mission, protocol dictates

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that the payload be operated by the INCO (Integrated Communications Officer) in the Mission Control Center (MCC) at NASA Johnson Space Center (JSC). This warrants a novel operations architecture for the system which we describe here.

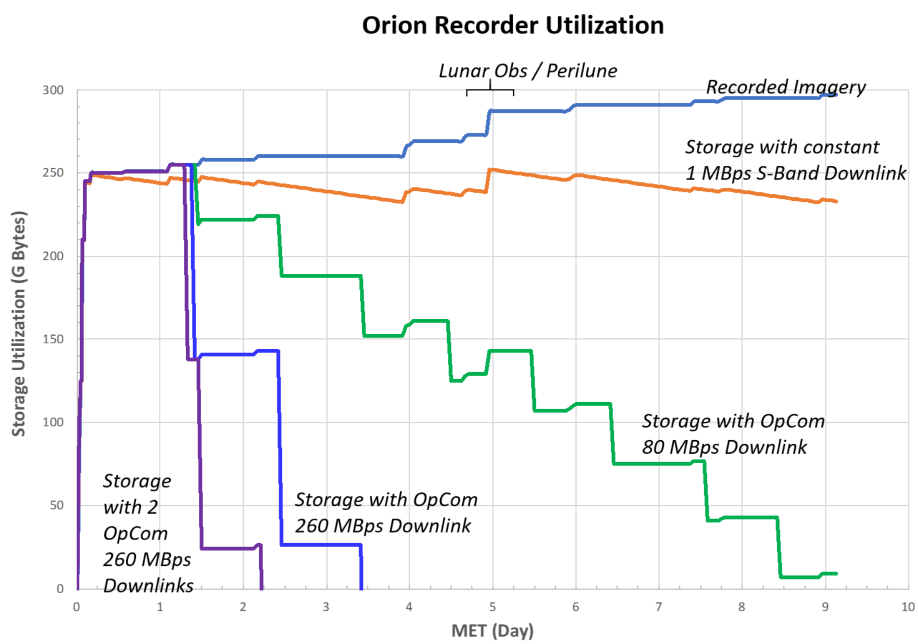

Figure 1: Projected data stored as a function of mission time for Artemis II mission using S-Band, 80 Mbps Opcom, and 260 Mbps OpCom.

2. LASERCOM MISSION LEVEL ARCHITECTURE

The O2O lasercom system, shown in Figure 2, consists of 4 major system elements: Orion Spacecraft Element, the Space Terminal Element (STE), the Ground Segment, and the Orion Ops Element [2]. For this mission, there are several players including MITLL, NASA GSFC, NASA JSC, and NASA Jet Propulsion Lab (JPL).

1. The Orion Spacecraft Element consists of the Onboard Data Network (ODN) and Orion Utility Network (OUN). The Gb Ethernet interface to the STE (i.e. the lasercom terminal, what we are calling OpCom payload) is via a utility switch which operates at Layer 3. This switch in turn connects to another switch as well as to applications such as file transfer and real time video downlink.

2. The Orion Operations Element, located at NASA JSC, consists of the Mission Control Center (MCC), the Lasercom Space Terminal Console (LSTC), and Lasercom Planning and Analysis Center (LPAC). The MCC contains multiple distinct Flight Control Rooms (FCRs) plus several other support rooms to train for and operate missions. The INCO is responsible for overall OpCom payload (STE) operations. The LSTC provides real-time support to the MCC and the LPAC is responsible for longer-term analysis and end-to-end comm performance reports. The MCC is the end-user for the communications link, receiving video and file application data from the Orion spacecraft element. The key operator of the overall OpCom system operation is the INtegrated Comm Officer (INCO). The INCO also:
   - Activates the system before every pass, monitors system performance, and safes the system once the pass is completed.
   - Serves as the primary interface to the LSTC support console and provides status on OpCom operations.
   - Plays the traffic cop role for data flows over the optical link at any given time, as there is no router feature onboard
   - Takes responsibility for the Orion video system and downlinking video sources
   - Is responsible for the Orion Utility Network (OUN)

3. The Space Terminal Element (STE) is the OpCom payload installed on the Orion Spacecraft (on the crew adaptor ring) which serves as the lasercom space-side terminal. At a high level, it provides a 1-GbE data interface to the Orion Spacecraft Element and a free space lasercom transmit/receive gimballed interface to/from the earth. For command and telemetry, the STE employs an RS-422 interface to the spacecraft. OpCom transmits a 1.5-micron laser modulated which provides downlink/return communications data rates of 20, 40, 80, 130, 190, or 260 Mbps. It also receives both an uplink/forward communications link with 10 or 20 Mbps as well as a modulated beacon laser to aid with pointing and tracking. Pointing and tracking the beam is accomplished using real-time control loops that point a gimballed telescope and use fast steering mirrors to track out spacecraft jitter. When the payload is launched, the gimbal is latched, using a High Output Paraffin Actuator (HOPA), to prevent contamination on the telescope optics.

4. The OpCom Ground Segment consists of 3 sub-elements and the Ground Segment Operations Concept is described in Ref. [8].
    - The Ground Segment Operations & Analysis (GSOA) provides a single point of contact for both physical terminals and the data element.
    - The Ground Data Element (GDE) provides an interface to the high-speed Ethernet data collected from the ground terminals. One key item to note is that the 1 Gb Ethernet interface from the ground terminal is broken up into uplink and downlink directions which is then combined into a single GbE interface using the GDE.
    - The Ground Terminal Elements (GTE) are the physical optical terminals. Since laser communications does not penetrate clouds, it is prudent to have multiple optical receive terminal, especially for a short mission such as Artemis II. For this mission, there are two ground terminal locations – one at White Sands Complex in New Mexico and one at Table Mountain Facility in California.

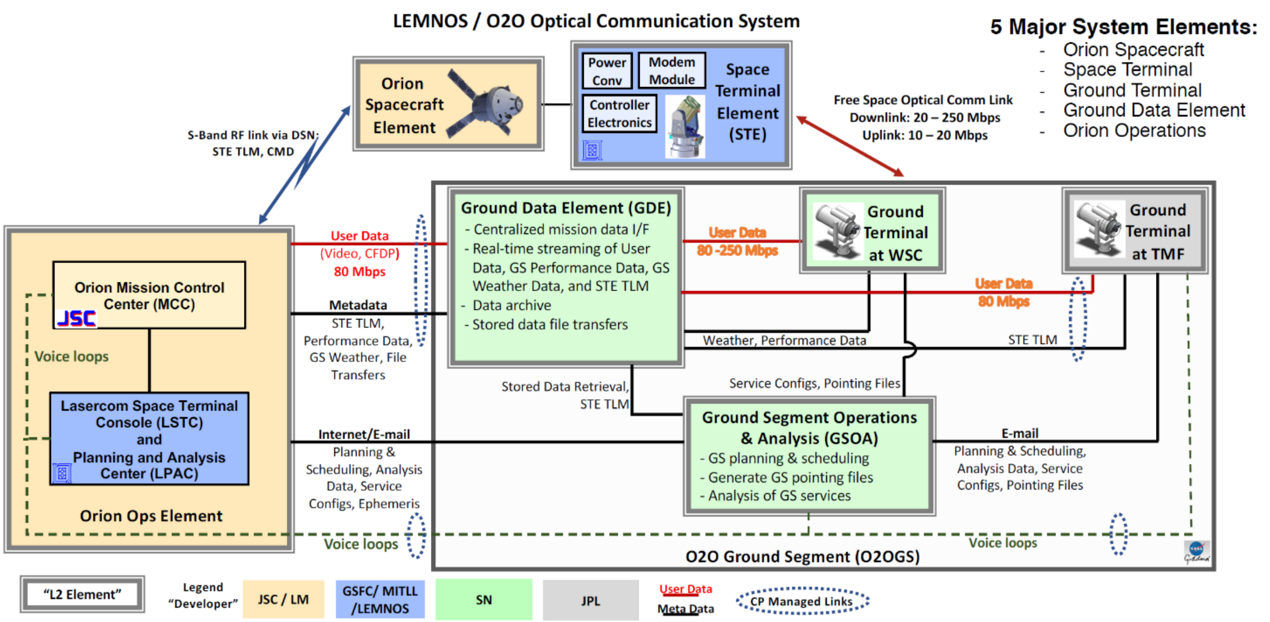

Figure 2: Mission level architecture diagram.

3. LINK OPERATION PLANS

A notional high-level timeline for operating the OpCom system is shown in Figure 3. The Artemis II mission begins with a High Earth Orbit (HEO) to checkout systems and begins the lunar outbound trajectory which takes about 4 days. This is followed by a lunar orbit and then a 4-day lunar return and entry. Just prior to earth entry, the crew adaptor ring and the service module are jettisoned.

OpCom will be commissioned on Mission Day 1, during the HEO operations. The commissioning is divided into two parts: payload activation and system calibration. Activation can take place without line of sight to the ground terminal. During activation, the payload is powered on for the first time. A health check is run to determine payload health. Data from the built-in star tracker is examined and compared to Orion's star tracker data. Once these checks are complete, the HOPAs are activated (melted) which "pops" open the gimbal latch. Once unlatched, the gimbal is exercised over its range of motion. The health check is repeated with the latch open and with the gimbal actively pointed back at the latch. The gimbal is then driven to point at predetermined locations to validate the computed azimuth and elevation angles without light being transmitted at this time. The communications side of the OpCom payload is also checked out using a loopback mode on the payload modem. This completes the activation phase.

The next step is the system calibration event. During this event, the cooperative acquisition process is exercised. In order to track on the narrow optical beams, the OpCom payload has to point its acquisition sensor towards a ground terminal. The pointing of the telescope relies on a navigation packet provided by the Orion spacecraft which contains time as well as spacecraft position and attitude. The payload uses this information along with predetermined calibration matrices to transform the Orion attitude to the OpCom payload attitude. In order to acquire the ground transmitted beacon, the gimbal will scan open loop until it sees an incoming beacon signal. Once the ground signal is acquired, the difference between the open loop pointing and the acquired pointing can be used to re-calibrate the onboard attitude transformation matrices if any movement has occurred due to launch loads.

Once the calibration is complete, the OpCom system may be used for communications. It functions like a transparent bridge, effectively a "wire." Once the communications link is established, it can be used for file transfers and real-time video. The goal of this mission is to explore and utilize the operational performance envelope and monitor performance during motion of solar arrays, crew exercise, thermal effects, thruster fires along with having the optical link go through different elevation angles, atmospheric effects, and to different ground terminals.

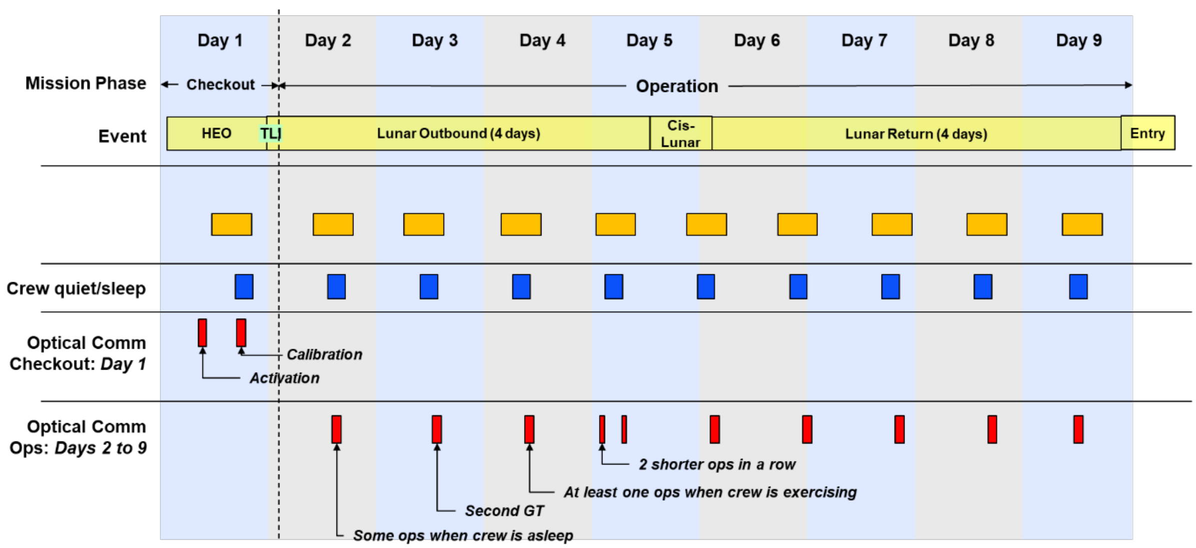

Figure 3: High level mission timeline.

When not in use, the payload is put in a "gimbal hold" mode which is a low power mode in which the gimbal is made to point at the latch and held there by the controller for safety from debris and Orion waste products.

The on-board software architecture has been designed to safely operate the payload using only a handful of commands/macros[2] under typical circumstances. As such, there is a subset of commands/macros that are explicitly labelled by Compact Unique Identifiers (CUIs) which makes them readily available to send from MCC. These commands have been tested at Lockheed Martin's Integrated Test Lab (ITL) and a follow-up test will occur from MCC in early 2023. For

[2] A macro is an onboard program which can run many commands and employs simple language to allow for conditional statements, loops, etc.

contingencies, the payload software architecture contains macros which can be called up using their own internal identifying number. Finally, there is a command structure called “block” command which facilitates uplink file transfers to the payload controller electronics as well as any commands that are not explicitly called out in by CUI.

4. CONCLUSION

The OpCom payload on the Orion spacecraft will facilitate mission video uploads and downloads, file transfers, and real-time video conferencing during the Artemis II crewed mission. OpCom has been designed to be run from the Mission Control Center by the INCO using very simple commands.

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