NASA's Deep Space Optical Communications – an Update

Abhijit Biswas
Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109
Abhijit.Biswas@jpl.nasa.gov

Abstract: NASA is developing a new space and ground technologies to demonstrate deep space optical communications in the 2022-2024 time frame. This paper provides an update on the status of this development.

1. Introduction

1.1. Motivation

The demand for returning larger data volumes from NASA's deep space missions continues to grow [1] in order to support higher resolution science instruments, human exploration of space and to exercise a virtual presence by streaming high definition imagery. State-of-art telecommunications systems are subject to bandwidth allocation restrictions and will not be able to meet the demand. Free-space optical communications has long been considered a viable means of augmenting NASA's communication tool box. Several successful demonstrations as far as lunar distances [2] have recently been completed but the formidable challenge of implementing optical systems to operate from planetary ranges lingers. Defining link difficulty as the product of data-rate × distance^2, the increase in difficulty to communicate from the Mars farthest range relative to the Moon is 60 dB or a million-fold.

1.2. Technology Demonstration Architecture

Overcoming the formidable difficulty requires new space and ground technologies. The Deep Space Optical Communications (DSOC) Project [3] funded by NASA and executed at JPL has been developing a flight laser transceiver (FLT) and two ground stations for transmitting high power lasers and receiving faint laser signals from deep space. NASA's upcoming Psyche Mission [4] manifested for launch in August 2022 plans to host the FLT while the Ground Laser Transmitter (GLT) will use the existing Optical Communication Telescope Laboratory (OCTL) located near Wrightwood, CA and the Ground Laser Receiver (GLR) will utilize the Hale telescope located at Palomar Mountain, CA. Figure 1 shows the technology demonstration (TD) architecture alongside the Psyche spacecraft trajectory.

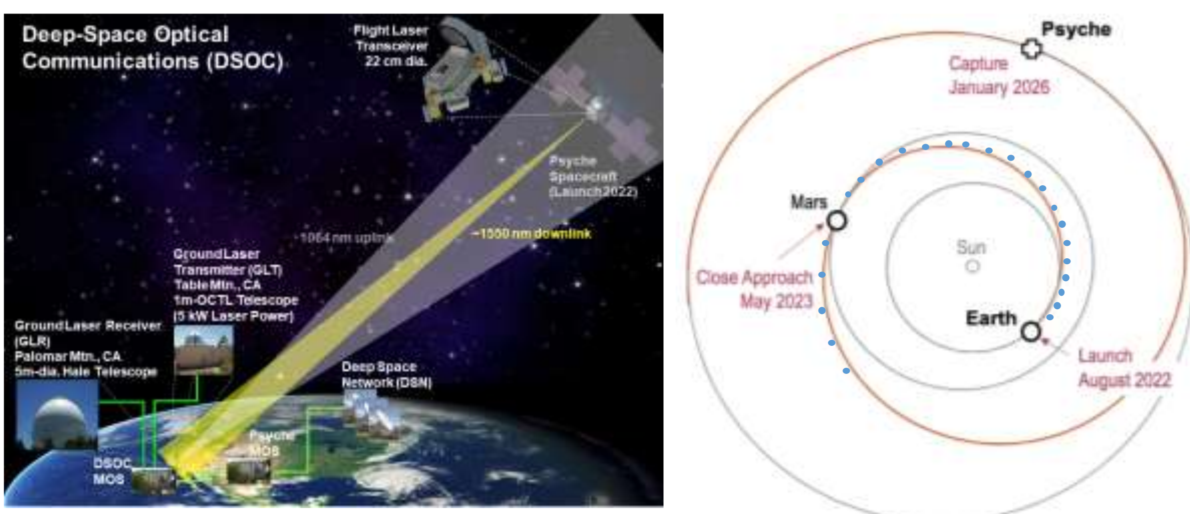

Figure 1 DSOC TD architecture (left); Psyche spacecraft trajectory, blue dots indicate potential space-ground optical link contacts.

The TD is planned for the first year after launch extending to deep space range of approximately 2.6 astronomical units (AU). A healthy FLT at the end of one year will not preclude extending the TD beyond the first year.

2. Concept of Operations and Approach

A 5 kW average power 1064 nm beacon laser from GLT will be used to illuminate the spacecraft. A minimum mean irradiance (~4 pW/m^2) will be required at the FLT aperture. Multiple incoherent laser beams will be transmitted and intensity averaging in the far-field will mitigate excessive irradiance fluctuations due to atmospheric turbulence. 10×500 W fiber amplified lasers will be coupled to the OCTL telescope with designs for handling the high average power to avoid damage to optics and coatings. Outdoor laser safety to avoid illuminating overflying aircraft and spacecraft will be implemented by shuttering the beam exiting the telescope.

During a TD contact the spacecraft will coarsely point the FLT in the direction of the beacon while the Psyche spacecraft feeds DSOC with on-board pointing knowledge. Custom struts built into the FLT will allow two-axis actuation for implementing a spatial scan with the 22 cm diameter transceiver, to search out the spacecraft pointing uncertainty region. The scan is designed to support a high probability of acquiring the beacon, assuming that the GLT is illuminating the FLT aperture with requisite irradiance. Successful acquisition will result in the beacon being detected by a sensitive single photon sensitive camera at the FLT focal plane. The camera output will be processed so that the modulated beacon signal is exploited to discriminate against additive background noise from earth reflected and stray sunlight, as well as, receiving low rate uplink data out to 1 AU. After acquisition, the weak beacon signal is tracked with relatively low bandwidth closed loop control. During tracking, centroid estimation of the detected beacon spot will generate an error signal for the pointing control. In the beacon tracking mode the line-of-sight will be adequately stabilized to allow pointing of the 1550 nm downlink laser back to the GLR.

A point-ahead mirror in the downlink transmit light path will point-ahead to account for the relative transverse velocity between the spacecraft and earth and the light time. The with so that the FLT can use built-in actuators to search and fine-point the 22 cm diameter FLT to sense the beacon signal with a photon-counting camera (PCC) at its focal plane. The beacon is modulated so that the PCC backend electronics can implement spatial and temporal acquisition schemes that discriminate against the additive background noise from Earth reflected sunlight and stray light. Following beacon signal acquisition closed loop control with the beacon centroid estimation serving as the error signal is exercised. This stabilizes the line-of-sight with < 3 μrad level mispoint. An actuated 2-axis mirror in the 1550 nm transmit laser path implements the point-ahead angle using on-board ephemeris knowledge. The 1550 nm downlink is received at the GLR where the 5m aperture diameter Hale telescope collects sufficient signal to focus the signal onto the ground tungsten silicide superconducting nanowire single photon detector (SNSPD) array. The downlink signal uses a serially concatenated pulse position modulated (SCPPM) modulation and coding scheme. A channel inter-leaver will mitigate pointing induced fades. A time-to-digital converter (TDC) streams timestamps processed for temporal synchronization, de-interleaving and error correction.

3. References

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[2] Don M. Boroson et al., "Overview and results of the Laser Lunar Communication Demonstration," in Proceedings of the SPIE, 8971, 8971OS-1-11, 2014.

[3] Abhijit Biswas, Meera Srinivasan, Sabino Piazzolla, Daniel Hoppe, "Deep Space Optical Communications," in Proceedings of the SPIE, 10524, 10524OU-1-11, 2018.

[4] David Y. Oh, Steve Collins, Dan Goebel, Bill Hart, Gregory Lantoine, Steve Snyder and Greg Whiffen, "Development of the Psyche Mission for NASA's Discovery Program," 35th International Electric Propulsion Conference, Georgia Institute of Technology, Oct. 2-8, 2018.

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