The architecture of the laser communications relay demonstration ground stations: an overview

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ABSTRACT

NASA’s Laser Communication Relay Demonstration (LCRD) will be NASA’s first long-duration demonstration of laser communications (lasercom) in space, providing geosynchronous-satellite-hosted bidirectional relay services between two Earth ground stations. LCRD will leverage and enhance existing ground stations. Ground Station 1 (GS-1) will leverage the Optical Communications Telescope Laboratory (OCTL) built by JPL, while Ground Station 2 (GS-2) will leverage the Lunar Laser Communications Demonstration (LLCD) Ground Terminal (LLGT) built by MIT Lincoln Laboratory. While each ground system has unique telescopes and integrated optics, many of the backend subsystems (e.g., communications, environmental monitoring, control, user simulators) will be common to both terminals. Here we provide an overview of the architecture of the LCRD ground stations, and the planned enhancements to the existing facilities.

Keywords: Laser communications, lasercom, adaptive optics, free space optical communication, deformable mirror, wavefront sensing, telescope, relay

1. INTRODUCTION

The NASA Laser Communication Relay (LCRD) mission will demonstrate reliable and cost-effective laser communication relay services between a geosynchronous (GEO) satellite lasercom terminal and two independent earth ground stations. Over LCRD’s two year mission, data and telemetry will be collected over the LCRD network and used to characterize optical communications, tracking, and acquisition performance under the varying environmental conditions, providing knowledge and operational experience that will enable NASA to design, procure, and operate future lasercom-empowered systems and networks [1].

Rather than develop new ground stations for LCRD, NASA will leverage and upgrade existing ground assets to accommodate the goals of the LCRD mission. The first ground station (GS-1) will be an upgrade of the Jet Propulsion Laboratory’s (JPL’s) Optical Communications Telescope Laboratory (OCTL) at the Table Mountain Facility located near Wrightwood, CA, USA. The second ground station (GS-2) will be an upgrade of the NASA-funded, MIT Lincoln Laboratory-built Lunar Lasercom Ground Terminal (LLGT) to be deployed at the White Sands Complex (WSC) in White Sands, NM, USA [2].
Rather than build a mission-specific satellite, NASA has chosen to have the LCRD flight payload hosted on board a commercial GEO communications satellite. Launch is scheduled for the December 2017 time frame.

Figure 1 presents a high level overview of the LCRD system architecture. The LCRD flight payload will be hosted on board a Space Systems / Loral commercial geosynchronous communications satellite. The flight payload will include two independent lasercom terminals, an electronic network to interconnect the two terminals and to interface with the host spacecraft, and the control systems and telemetry systems. The flight payload will be able to communicate optically over free space links to the two ground stations. The spacecraft will have an RF link to the Host Mission Operations Center (HMOC). Both ground stations and the HMOC will be able to communicate with the LCRD Mission Operations Center (LMOC) via the NASA Integrated Services Network (NISN).

![Figure 1. LCRD System Architecture. GSFC = NASA Goddard Space Flight Center, Greenbelt, MD, USA.](image)

A relevant Near-Earth mission, into which LCRD lasercom technology and experience could be infused in the future, is depicted in Figure 2. The Tracking and Data Relay Satellite System (TDRSS) includes a constellation of GEO communications satellites that can communicate with various user platforms, including other GEO and LEO satellites.

Figure 3 depicts a concept for a future hybrid optical/RF space network that takes TDRSS a step further, incorporating optical communications links to provide a variety of services to multiple LEO and ground assets. This network will provide simultaneous support of multiple real-time users and multiple store & forward (non-real-time) users, multiplexed onto the same optical trunk line. This future network will support both scheduled and unscheduled handovers between Ground Stations to accommodate weather blockages.
Figure 2. Design reference mission – TDRS = Tracking and Data Relay Satellite, in GEO, communicating with LEO and earth ground-based assets.

Figure 3. Future hybrid optical/RF space network concept, inspired by TDRSS, infused with LCRD lasercom technology. A single GEO satellite can communicate with multiple User S/C and with multiple GSs. The GSs are connected via terrestrial network to the LMOC and the various User MOCs. S/C = spacecraft, GS = ground station, MOC = Mission Operations Center, LMOC = LCRD Mission Operations Center; m is the number of GSs, n is the number of user S/C, and k is the number of User MOCs. Solid red lines depict the two lasercom links to be demonstrated during the LCRD mission, while the dashed red lines depict the future scaling of this network to many users, both in space and on the ground.

Based on this reference design mission and goals for infusing the LCRD lasercom technology into a space network, a set of requirements for the LCRD mission has been developed. Top level requirements for the mission include:

1) The LCRD shall enable demonstrations of operational optical relay communications architectures
2) The LCRD shall provide bi-directional direct optical communications services between Earth and GEO
3) The LCRD shall enable bi-directional direct optical communications services between low earth orbit satellites (LEO) and GEO
4) The LCRD shall provide relay services
5) The LCRD shall provide two simultaneous bi-directional optical relay services from GEO
6) The LCRD shall provide services using pulse position modulation (PPM)
7) The LCRD shall provide services using differential phase-shift-keying (DPSK) modulation
8) The LCRD shall measure and characterize system performance for the life of the mission
9) The LCRD shall be a NASA Class D mission (technology demonstration)
10) The LCRD shall be designed for a minimum 2-year mission life

The envisioned network architecture also motivates several classes of planned experiments for the LCRD mission. One such class encompasses real-time relay services between the two GSs, with one GS emulating a User platform (LEO terminal), using either of the two modulation formats (DPSK, PPM). Another class is direct communication between a ground station and the GEO flight payload, using either modulation format. Because the links involving the ground terminals are subject to weather blockages, and because User platform orbits are highly transverse-velocity mismatched to the GEO orbit, handovers of direct links will also be performed between ground stations.

Above, we provided a very high level view of the architecture for the LCRD mission and a vision for its scalability. In the sequel, we examine the subsystems comprising the two ground stations. Figure 4 is a block diagram applicable to either ground station. Subsystems depicted with green blocks denote elements that will be duplicated, one for each ground station. The gray blocks denote items that are unique to each ground station, as each of these subsystems was developed independently, for prior applications. The LMOC and Testbed are singular entities.

Figure 4. LCRD Ground station configuration block diagram. Blocks in green are common elements for both GS-1 and GS-2. The telescope, integrated optics, and laser safety systems are unique to the two ground stations. The LMOC and Testbed are singular entities. M&C = Monitor & Control, Comm = Communications, Pltfm = Platform, Sim = Simulator, LAN = local area network, LMOC = LCRD Mission Operations Center, User = a distinct platform that can communicate with the LCRD flight payload.

The telescope assembly subsystems must be capable of pointing towards the LCRD flight payload terminals to support acquisition of, tracking of, and communication with the flight terminals (one flight terminal at any given time). This includes supporting the transmission of beacon laser light and communications signal laser light. The telescope assembly must also be capable of receiving downlink beacon and signal laser light from the flight payload. GS-1 will use a singular one-meter telescope for transmit and receive, while GS-2 will use a subset of the four 15 cm uplink telescopes and 4 downlink 40 cm telescopes used for the LLCD mission.
The integrated optics subsystems couple the communications subsystems to the telescope assembly subsystems. In the receive optical paths, both GS-1 and GS-2 will be equipped with adaptive optics systems to correct the wavefront distortion of the downlink beams. GS-1 will use a conventional, Shack-Hartmann wavefront-sensor-based adaptive optics system. For GS-2, a hardware study is underway to assess the relative merits of conventional adaptive optics vs. a multidither adaptive optics system [3], for a 40 cm telescope in the context of the LCRD application. This hardware study will be complete in the first half of CY2013. An adaptive optics system will be built for only one of the GS-2 receive telescopes. Adaptive optics is not required for the LLCD mission because a spatially multimode, optical-phase-insensitive photon counting receiver is to be used for the LLCD downlink pulse position modulation (PPM) waveform. However, in addition to PPM, LCRD will support differential phase-shift keying (DPSK) and will utilize single-mode optical preamplified receivers to accommodate that waveform, necessitating the use of adaptive optics for wavefront correction, to enable efficient optical coupling into single mode fiber.

The communications subsystem, on the transmit path, converts incoming electrical data from the user services gateway to intensity/phase modulated optical signals to be sent to the integrated optical subsystem, and performs the reverse on the downlink path. Functions of the communications subsystem include frame and slot synchronization, frame delineation, encoding/decoding, (de)interleaving, and (de)framing of the data. Coding and interleaving help to ensure robust communications in the presence of fading resulting from propagation through the optically turbulent atmosphere.

While the communications subsystem operates at the physical and data link layers, the user services gateway (USG) performs processing at the higher network layers. The USG supports both real-time traffic and non-real-time store and forward traffic flows. The USG can (de)multiplex multiple users using any of a set of allowed traffic flow types, command streams and telemetry streams. The USG also provides flow control policing of offered flow rates for user MOC data services destined for the uplink to the GEO flight payload. The USG provides rate matching between uplink-bound traffic flows and the communications subsystem.

The User Simulators include both User Platform Simulators and User MOC Simulators. The User MOC simulators emulate virtual ground operations centers, while the User Platform Simulators emulate LEO spacecraft optical links. Because a User platform would pass data directly to the GEO flight payload, rather than through the USG, the USG has a bypass mode for User Platform Simulators to communicate directly with the communications subsystem, with the GS communications subsystem emulating the LEO spacecraft’s communications subsystem.

Thus far, we’ve focused on the data path through a ground station. Other critical functions include atmospheric/environmental monitoring, laser safety systems, and command, control, and telemetry. Atmospheric monitoring instruments include sun photometers to measure atmospheric transmission, scintillometers to measure optical turbulence, and cloud cover monitors.

GS-1 is equipped with the comprehensive Laser Safety System from OCTL (LASSO) that automatically shutters the laser when an aircraft is detected or a satellite is at risk of transiting the laser beam as predicted by US Strategic Command’s Laser Clearing House. Figure 5 shows the LASSO wide (46° x 35°) and narrow (12° x 9°) field-of-view (FOV) long wave (8-14 μm) infrared cameras that detect aircraft out to 3.4km, and the radar that detects aircraft out to 58km at 20 degree elevation. GS-2 will be located in controlled airspace and will operate in coordination with the White Sands Complex (WSC) air traffic control system. GS-2 therefore does not require an automatic aircraft detection system.
The ground station monitor and control software systems are depicted in Figs. 6 and 7. The architecture incorporates an operator interface, a scheduler, a local telemetry server, a centralized command processor through which all local commands flow, and interfaces to each of the GS subsystems. The operator is fed telemetry from the telemetry server, and issues commands into the command processor, which in turn interprets and distributed commands to the appropriate subsystems. The LMOC also receives telemetry from the telemetry server, and the LMOC issues control messages that are sent through the command processor. The scheduler orchestrates the distribution of commands by the command processor by issuing a dynamic schedule to that processor. Where the monitor and control software systems differ between GS-1 and GS-2 are in the interfaces to the subsystems, where legacy ground system software is leveraged where appropriate.
Figure 6. GS-1 Monitor and Control Software System Block Diagram. Subsystems and message type acronyms: LCRD Mission Operations Center (LMOC), LAser Safety System at OCTL (LASSO), Integrated Optics System (IOS), User Services Gateway (USG), Communications Subsystem (COMM Sys) Telescope Control System (TCS), Commands (CMDS), Control Messages (CTRL MSGS).

Figure 7. GS-2 Monitor and Control Software System Block Diagram. Subsystems and message type acronyms: LCRD Mission Operations Center (LMOC), User Services Gateway (USG), Communications Subsystem (COMM Sys), Executive Control System (Exec CTRL), Commands (CMDS), Control Messages (CTRL MSGS).

The table in Fig. 8 summarizes some of the distinct features of the two ground stations. GS-1 is in the mountains of southern California, while GS-2 is in the desert in New Mexico at a significantly lower altitude. The distinct weather patterns of these two locations will provide site diversity, decreasing the probability
that a weather blockage at one location will be contemporaneous with a weather blockage at the other site, and thereby increasing the probability of at least one optical link being available at any given time. A single large aperture is used in GS-1, whereas GS-2 uses separate transmit and receive telescopes (and trackers). The adaptive optics (AO) system for GS-2 is still being evaluated in a hardware study, but may be a multidither based AO system, in contrast to the conventional AO system adopted by GS-1. Finally, the laser safety system at GS-1 is quite sophisticated, whereas GS-2 is in controlled airspace and merely requires coordination with the WSC air traffic control system.

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<th>Locale</th>
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<th>GS2</th>
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<td>Dither AO</td>
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<td></td>
<td>3-Tier Laser Safety System at OCTL</td>
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Figure 8. Table summarizing some of the distinct attributes of the two LCRD ground stations. WFS = wavefront sensor, AO = adaptive optics.

In summary, we have described the goals and objectives of the LCRD mission and described the optical ground stations; their common elements and their unique legacy features. The two-year LCRD mission is the path forward to NASA's future hybrid optical/RF TDRSS to provide high bandwidth support for its space network. LCRD will demonstrate a variety of operational scenarios while taking advantage of the site diversity afforded by the California and New Mexico ground stations.

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REFERENCES