NASA's Optical Communications Program for Future Planetary and Near-Earth Missions

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Introduction: NASA's Space Communications and Navigation (SCaN) Program within the Human Exploration and Operations Mission Directorate (HEOMD) at NASA HQ is pursuing a vibrant and wide-ranging optical communications program for future planetary and near-Earth missions following the spectacular success of NASA's Lunar Laser Communication Demonstration (LLCD) from the LADEE spacecraft orbiting the Moon in 2013 and 2014.

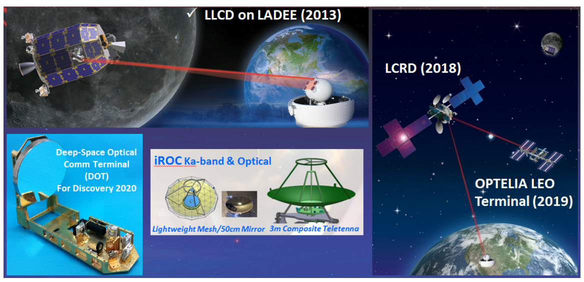

Fig-1: NASA's Optical Communication Program – the LLCD and LCRD missions, the proposed DSOC effort for Discovery 2020, and the ISS LEO-T and iROC efforts described in the paper.

Why Optical Communications?

Today's radio-frequency (RF) communications are the bottleneck for returning more science data from NASA missions, especially those from beyond geosynchronous Earth orbit (GEO). Free-space optical communication (FSOC) uses laser transmitters with wavelengths that are 10,000x shorter than those of RF, allowing much higher data rates. The LLCD mission demonstrated that laser communication could break through the RF bottleneck with data download speeds of 622 Mbps from 400,000 km in lunar orbit. This is almost an order of magnitude higher data rate from the Moon than our best Ka-band radio (100 Mbps on LRO in 2009).

Similarly, the transmit wavelengths of FSOC are 10,000x shorter than RF beams, allowing narrower beam divergences which translate to more concentrated communications power at the receiver and commensurately lower transmit powers to and from smaller and lighter apertures. This allowed LLCD to operate at higher data rates while using only half the mass (30.7 kg) and 25% less power (90W) than LRO (61 kg and 120W, respectively). Such improvements in the returned data volume and the size, weight and power (SWaP) are extremely attractive to NASA's future planetary missions.

LLCD also demonstrated a 20 Mbps uplink (which supported HD video) and sub-centimeter precision ranging while communicating. LLCD experienced perfect and near-instantaneous acquisition and tracking (PAT) of the 15 microradian beams on every pass while delivered The LLCD space terminal and primary ground terminal at White Sands, NM were both designed and built by MIT Lincoln Laboratory (MIT-LL), while alternate terminals were provided by NASA's Jet Propulsion Lab (JPL) at Table Mountain, CA and by the European Space Agency (ESA) in Tenerife, Spain. The LLCD terminal on LADEE demonstrated regular links and handovers (< 2 minutes) between all three ground stations during the mission.

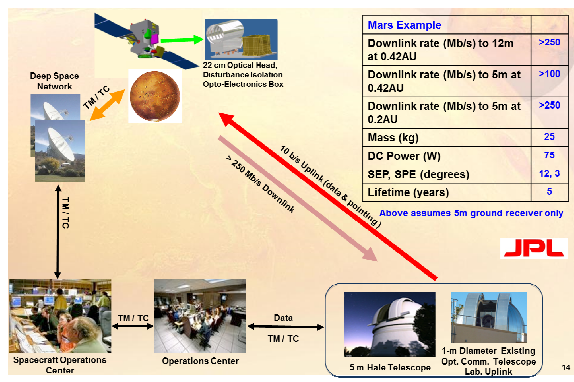

Fig-2: NASA JPL's Deep Space Optical Comm (DSOC) Project, providing up to 250 Mbps from Mars at opposition.

Laser Communications for Planetary Exploration: LLCD's historical success has given new impetus to NASA's Deep Space Optical Comm (DSOC) effort at NASA JPL. DSOC is designed to work from near-Earth asteroids to Jupiter and could deliver data at over 250 Mbps from Mars at opposition (0.42 AU), with a mass of 25 kg and using 75W, as shown in Figure 2. However, DSOC has additional challenges from LLCD, including a kilowatt-class uplink beam from the ground, a photon-counting detector array on the spacecraft to see that uplink beam, and an order-of-magnitude improvement for stable beam pointing and larger point-ahead angles for the downlink beam.

DSOC will also require large receiver apertures on the ground – ideally, DSOC would communicate with a 12 meter telescope, although current plans are to use the 5 meter Hale telescope on Mount Palomar to deliver >100 Mbps from Mars at opposition. Note that the highest RF data rate demonstrated from Mars is 6 Mbps from MRO's Ka-band transmitter, so DSOC represents an order-of-magnitude improvement. NASA's Space Technology Mission Directorate (STMD) and Science Mission Directorate (SMD) have recently teamed up with the HEOMD SCaN Program to take DSOC to TRL 6 by the end of FY17 so that it can be flown as GFE hardware on the upcoming Discovery 2020 mission.

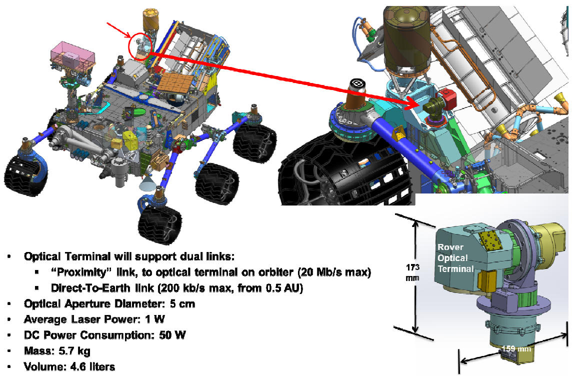

Fig-3: Proposed optical communications terminal on the Mars 2020 rover for both relay and direct-to-Earth (DTE) laser links.

The SCaN program has also supported a recent NASA JPL study to place a very small (~ 6 kg, 50W) lasercomm terminal on the Mars 2020 rover. This terminal could communicate to an optical relay terminal on a Mars orbiter at up to 20 Mbps (which of course requires such a terminal) or, interestingly, it could provide a "direct-to-Earth" (DTE) link from the Martian surface at up to 200 kbps, which is an order of magnitude better than the current X-band RF DTE link. This system will be based on a small (5 cm) transmit aperture and may find additional applications in low-Earth-orbit to ground applications for near-Earth lasercomm as well.

NASA Glenn Research Center (GRC) is investigating a hybrid RF-optical system, known as the integrated Radio and Optical Communication (iROC) which will incorporate a body-pointed 3 meter RF mesh antenna with a 30 cm optical telescope while sharing an integrated software-defined modem for both Ka-band and laser communications. This research effort is currently low TRL (2 to 3) but poses intriguing possibilities if the size, weight, and power of the system can stay somewhat within the SwaP of today's RF systems.

Near-Earth Lasercomm: NASA is also developing lasercom for downloading terabytes of data per day in the near-Earth environment. NASA-GSFC is building the Laser Comm Relay Demonstration (LCRD), which will place two high-bandwidth (1.25 Gigabits per second), LLCD-based lasercomm relay terminals as a hosted payload on a commercial communications satellite in geostationary orbit (GEO) in 2018. MIT-LL is the designer of the LCRD system and has successfully transferred the design for the primary components of LLCD, namely the gimbaled optical telescope and pointing controller, to industry. The LCRD mission is now procuring these components on fixed price contracts. The 1.25 Gbps Differential Phase Shift Keying (DPSK) Modem (Tx/Rx) modules will be commercialized in the near future.

Currently LCRD is planned to relay data between two ground terminals, however, NASA has tentative plans to place an LCRD terminal on the ISS (the ISS LEO-T mission) to fully demonstrate relay from low-Earth orbit through the LCRD terminals in GEO and then to the ground as an optical analog to our current RF-based Tracking and Data Relay System (TDRS). NASA eventually plans to offer these services to our next generation of Earth-orbiting scientific satellites to download ever more data from new, high-resolution instruments.

Finally, NASA is committed to build a network of optical ground stations to support these missions. We are currently performing studies to build additional stations (including a 12 meter aperture) in addition to the three stations (~ 1 meter apertures) used for LLCD Our next station may under the clearest skies possible in Hawaii to support optical communications on NASA's deep space and near Earth missions of the future.

References:

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