NASA’s Optical Communications Programs

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Resiliency is the ability of a mission to endure the loss of one or more nodes, satellites or ground system elements — perhaps degraded but still operational. The mission may continue to function by use of augmented capabilities available from other sources.

Resilience drives:
- Disaggregated systems
- Affordability to allow sparing and system redundancy
- Interoperability with other missions/systems
- Density of the constellation

Small optical communication systems can lead to large affordable constellations providing resilient communications in space
The NASA Space Network or Tracking and Data Relay Satellite System is comprised of a constellation of Tracking and Data Relay Satellites (TDRS) in geosynchronous orbit and associated ground stations and operation centers.

NASA is developing technologies for the next generation of relay satellites.
Scheduled launch: August 2020

Mission duration:
Two year ops demo
Six years ops

Hosted payload: US Air Force’s
Space Test Program Satellite – 6 (STPSat-6)

Ground stations:
California
Hawaii

Partnership:
NASA Goddard Space Flight Center
NASA Jet Propulsion Laboratory
MIT Lincoln Laboratory
STMD/Technology Demonstration Missions
Space Communications and Navigation

Flight payload:
• Two 10.8 cm Optical Modules and Controller Electronics Modules
• Two software-defined DPSK Modems with 2.88 Gbps data rate (1.244 Gbps coded user rate)
• 622 Mbps Ka-band RF downlink
• New High Speed Switching Unit to interconnect the three terminals

Key for NASA’s Next-Gen Earth Relay

Guest investigators welcome!
NASA’s Optical Plan Forward: User Terminals for LEO and the Moon

User Terminals for ISS and Orion EM-2

- Gen-1 GEO Optical Relay Terminal
- Laser Communications Relay Demonstration (LCRD)
  - 311 Mbps x 2 Return Links on RF
  - 16 Mbps Forward Link on RF
- Gen-1 Optical User Terminal
  - 1.244 Gbps Optical Return Link
  - 51 Mbps Forward Link
- Orion EM-2
  - Up to 531 Mbps PPM Return Link
  - 20 Mbps Forward Link

SCaN Operated Gen-1 OGS
- Gen-1 Optical Ground Station

Operations Center
TeraByte InfraRed Delivery (TBIRD)
200 Gbps Cubesat Demo in Early 2020

100+ Gbps optical link enables delivery of many TeraBytes/day from low-Earth orbit

Space terminal based on telecom optical components, small enough for CubeSat

~Foot-class ground terminal aperture is low cost and widely deployable

MIT
Lincoln Laboratory
TBIRD Proto-Flight HW at MIT Lincoln Laboratory based on Integrated Photonics and Coherent DSP ASIC

TBIRD
Mass: 2.24 kg
Power: 120W
(5 minute ops)
Volume: 1.8 U
NASA's Optical Plan Forward:
Deep Space Optical Communications (DSOC in 2022)

PPM Transmitter
With Photon Counting Receiver

DSOC Gen-1 Optical User Terminal
DSOC on Psyche Asteroid Mission 2023
125 Mbps from 40M km

DSOC Gen-1 Optical Ground Station

Operations Center
Laser Communications for Lunar Orbital Platform-Gateway

Optical Data Trunk to/from Earth
- 20+ Mbps Forward
- 1000+ Mbps Return

Gateway-Enabled Lunar Network
- High-rate, low-latency data
- Positioning, navigation and timing

CubeSat
- 4 – 500 Mbps

Lunar Surface
- 100 Mbps – 2.1 Gbps

Laser communications enables data returns from Gateway comparable to today’s ISS and high-rate proximity links for an optical lunar network.
Increasing Communications Resiliency Through Standardization and Resource Sharing

• Resiliency in both space and on the ground can be increased by sharing communications resources

• Sharing optical communication ground stations or relay satellites would also allow agencies to share the cost of the communications infrastructure.
  – For example, due to cloud blockage, it is critical to have multiple ground stations in use during space-to-ground optical operations to provide high availability.

• International cross support for civil space agencies is being worked within the Interagency Operations Advisory Group (IOAG) and the Consultative Committee for Space Data Systems (CCSDS).

• The goal is to develop optical communications cross support by various agencies as we have today in traditional Radio Frequency (RF) communications.
NASA and CCSDS International Optical Communication Standards in Development

- **100 Gbps**
- **10 Gbps**
- **1 Gbps**
- **100 Mbps**
- **10 Mbps**

**Commercial**
- LEO Crosslinks
- Or Direct-to-Earth Using OOK To Commercial OGS

**Next Gen IOC**
- **GEO**
- **MOON**
- **Lagrange**

**DSOC**
- **Psyche**
- **Gen 2 DSOC**

- **1 Gbps @ 1 AU**
  - SCaN Goal

**Range of Communication Link (km)**

- Light second
- Light minute
- Light hour

**Diagram Details**
- **TBIRD Demo**
- **LCRD**
- **EDRS**
- **JDRS**
- **LOP-G**
- **O2O**
- **OCSC**
- **PSK**
- **OGS**

**Networks**
- **COMMERCIAL**
- **LEO CROSSLINKS**
- **DIRECT-TO-**
  - **EARTH USING OOK TO COMMERCIAL OGS**

**Speeds**
- **102 103 104 105 106 107 108 109**
- **1 AU**

**Losses**
- **100X More Loss to PPM**
- **1,000,000X More Loss so PPM, Large OGS**

**Efficiencies**
- **CCSDS High Data Throughput**
- **CCSDS High Photon Efficiency**

**Applications**
- **Psyche**
- **Gen 2 DSOC**
- **TBIRD Demo**
- **Next Gen IOC**
- **O2O**
- **OCSC**
- **PSK**
- **OGS**
Detection Sensitivity in Optical Communications

- **Optically Preamplified**
- **Coherent**
- **Photon Counting**
- **Quantum Limit**

**Photons per bit**

- 10
- 1
- 0.1

- Received Signal → Optical Amplifier → Power Detection
- Received Signal → Local Oscillator → Linear Detection
- Received Signal → Photon Counter

- ASE noise limited
- LO shot noise limited
- "noiseless"

Unknown architecture

CCSDS Optical On-Off Keying
CCSDS High Data Throughput
CCSDS High Photon Efficiency PPM
Questions?

Please feel free to contact me at:

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BACKUP
Integrated Laser Communication Relay Demonstration Payload at NASA Goddard Space Flight Center
The Key to Reducing SWaP and Cost: Photonic Integrated Circuits

US Industry has commercialized “Integrated photonics” to allow many electro-optical components, even glass fibers, to be “squeezed down”....

For NASA, this means that optical systems for communications and sensors can be reduced in **size**, **mass**, and **cost** by >> 100x by leveraging this commercially-available technology (some customization may be required)
Clouds are primary source of attenuation

Characterization and prediction of the atmospheric channel are critical to inform space link handovers, select ground sites, and to maximize system availability.
High Data Throughput 1550 nm
Link Scenarios

Optical Link
RF Link

Space
Relay

Crosslinks

Optical or RF
Trunks

Optical Direct-to-Earth
Link

Atmosphere
High Data Rate 1550 nm Signaling Overview

CCSDS Transfer Frames

- Frame Sync Marker Attachment
- Slicer
- FEC: DVB-S2, RS, or G.975 I.3
- Convolutional Channel Interleaver

- Q-Repeat
- Physical Layer Framing
- Randomizer
- Modulation: Burst-Mode PSK@1550nm

To amplifier or telescope
Optical relay serves as a transparent link-layer bridge between User Platform and Ground Relay.