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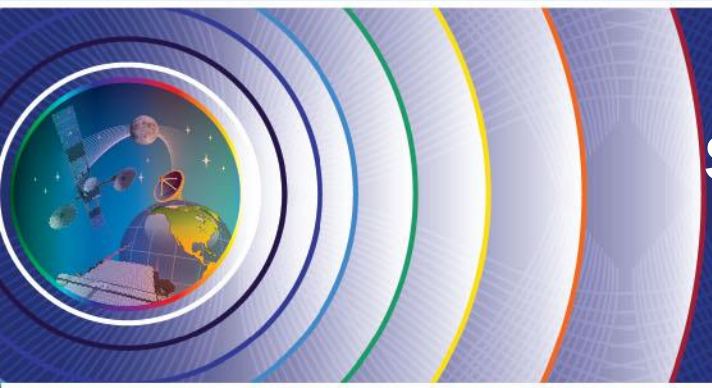

Considerations for an Earth Relay Satellite with RF and Optical Trunklines

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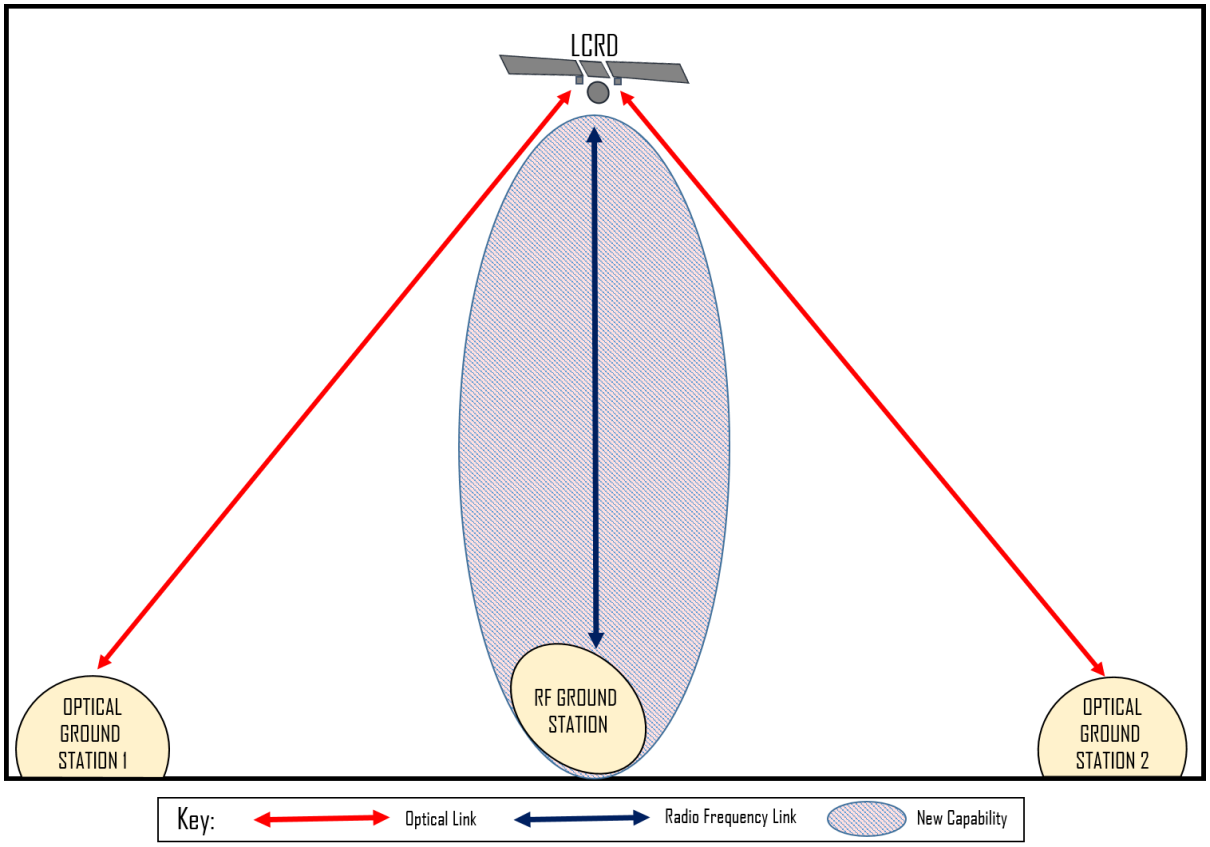
Laser Communications Relay Demonstration (LCRD) Mission

- LCRD mission is scheduled for a 2019 year launch
  - Two optical communications terminals and associated electronics as a payload on a satellite in geosynchronous orbit
  - Two optical ground stations for LCRD will be located in Southern California and Hawaii
  - Two years of optical communications services experiments and demonstrations
  - Up to five years of extended operations experiments and demonstrations
- This presentation will focus on the addition of an RF trunkline to combat the inevitable – clouds happen

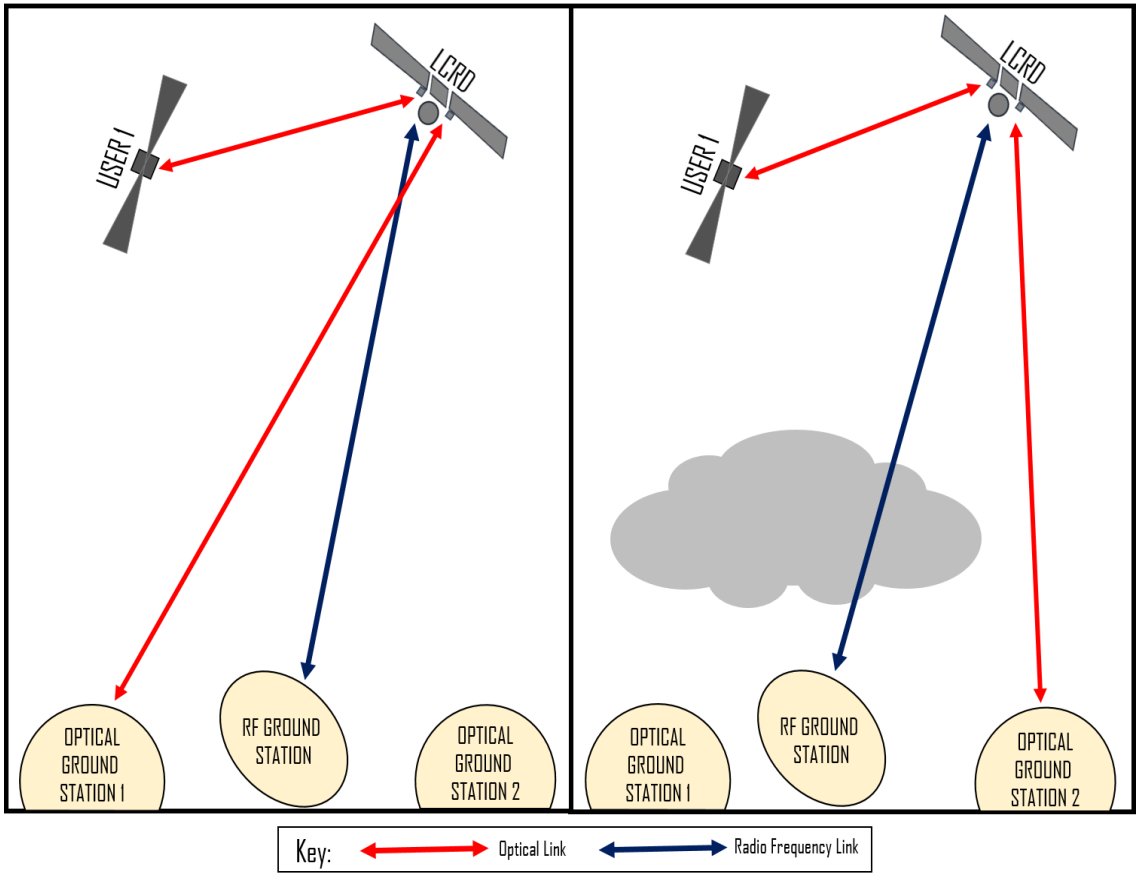
LCRD High Bandwidth RF Link



- LCRD has added a High Bandwidth RF (HBRF) system
  - Two optical links (1.244 Gbps Forward/Return Links)
  - Ka-Band RF (64 Mbps uplink/622 Mbps downlink)
- Allows each trunkline link type, RF and optical, to complement the other:
  - The optical link can deliver the data volume that is too much to fit within the RF spectrum
  - The RF link allows for some user data to be delivered while an optical outage occurs

Clouds Happen

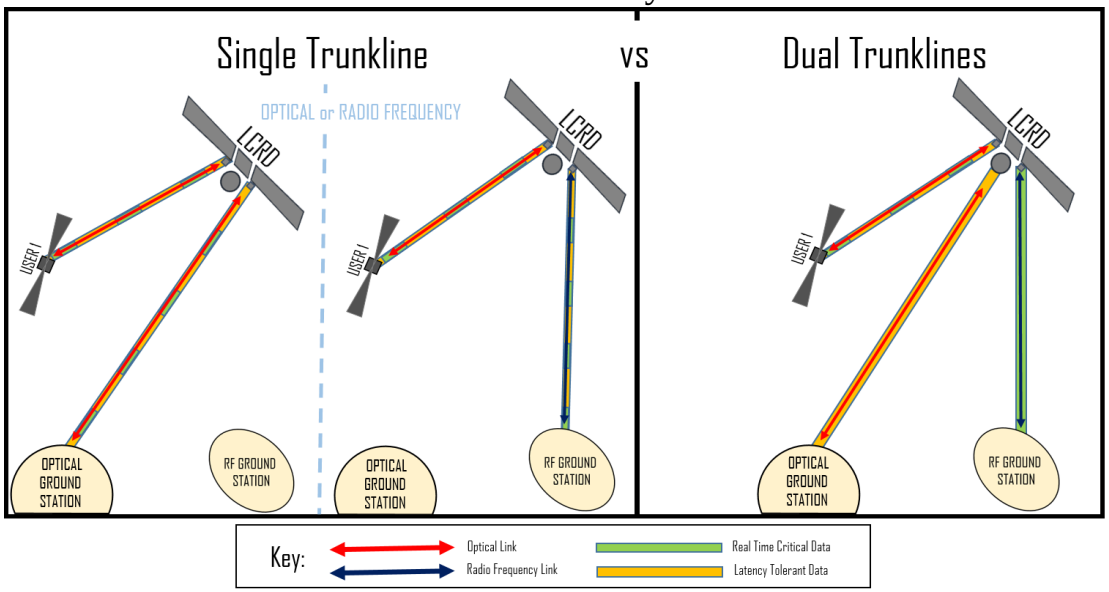
- Periodically a cloud will pass between a ground station and a spacecraft, and the link will be dropped.
- The assumption is made that some user data can tolerate the outages, usually by accepting delayed data delivery due to required retransmissions.



- Examples of data with realtime or very low latency delivery requirements:
  - Commanding
  - Telemetry
  - Science alerts
  - Voice
  - Video
- Examples of data that can be delayed as long as it is completely delivered
  - Science instrument files
  - Housekeeping files
  - Software uploads

Single vs Dual Trunklines

It is assumed that all RF and optical links are supported by modems in the flight payload, and, at minimum, the system is a demod/remod system.

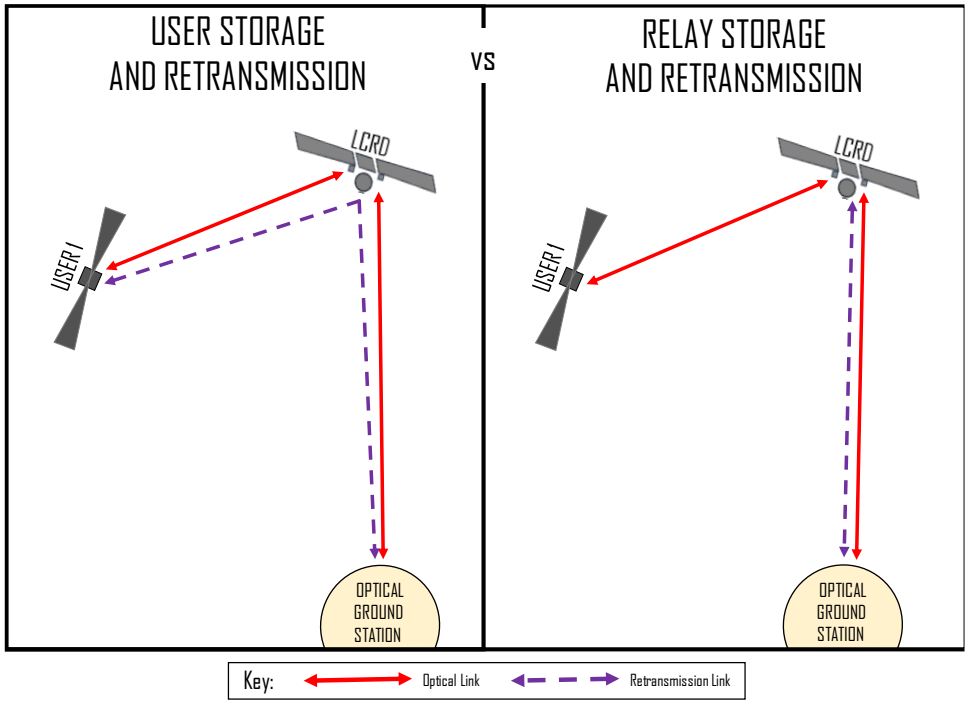


1. Data for a certain user either all traverses the RF trunkline or all traverses the optical trunkline
   - Simplifies payload requirements
   - No onboard processing required beyond basic modulation and demodulation
   - If the user data rate fits within the available bandwidth, delivery would be guaranteed through the RF trunkline
   - If user requirements are met with possible latencies, the optical trunkline would deliver a higher data volume.
   - leads to scheduling constraints and link utilization inefficiencies.

2. A portion of the RF or optical trunkline is allocated for use, an additional user service can only be added if it all fits into either trunkline, switching the data paths at the frame level.
   - Allows each trunkline to be better utilized given both realtime and latency tolerant data
   - User data would be transmitted in a defined common frame format so the relay's onboard processing could switch the frames between destinations as they are received
   - User systems would be required to not only frame their data, but to also mark each frame in a defined way to indicate

Storage and Retransmission

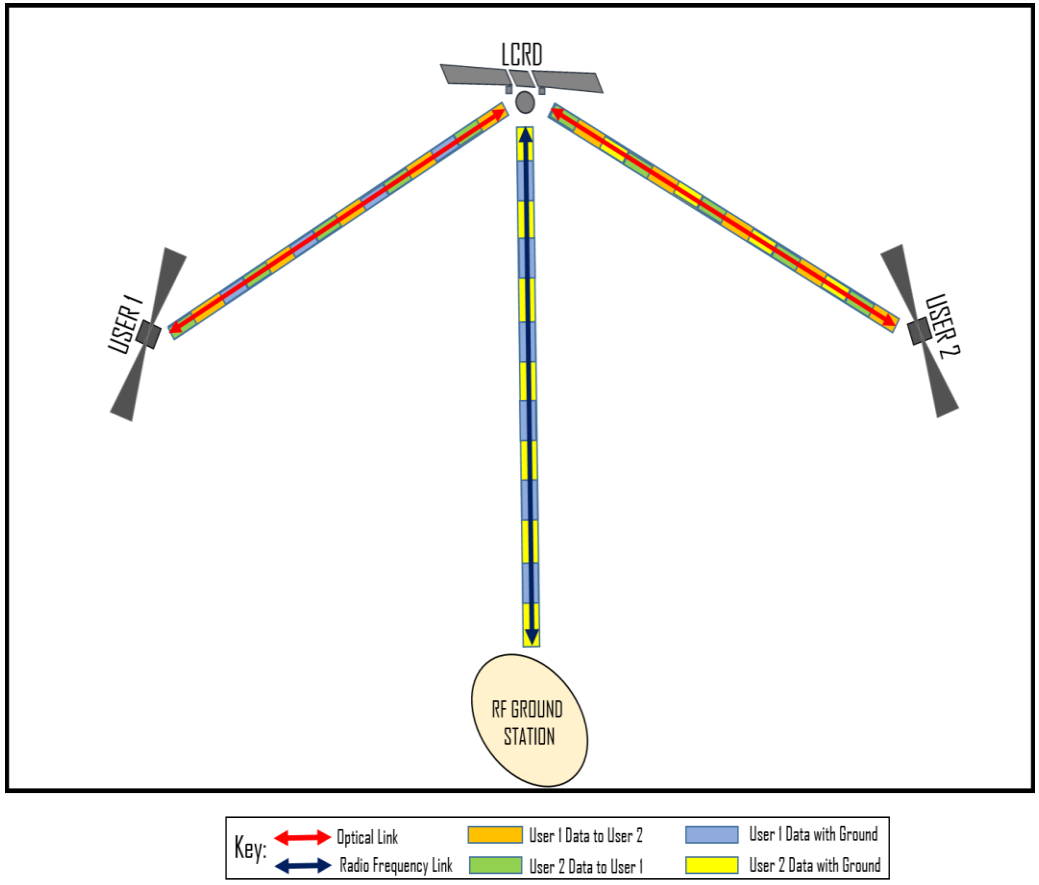
- If a relay payload included the necessary channel encoders, channel decoders, frame processing, and storage, storage and retransmission can be moved from the user spacecraft to the relay.



- This is a significant increase of complexity for the relay payload, but provides the following efficiencies for the user spacecraft:
  - Allows the trunkline to be packed even more efficiently
  - Provids a means for rate buffering and rate matching between available trunkline bandwidth and user link data rates
  - Allows the decoupling of the user optical link channel coding and link protocols from those used for the trunklines

- The DTN protocols can be implemented on user spacecraft and the relay ground station independent of the relay payload; providing the storage management and retransmission protocols required for operation with inevitable optical link outages. The core DTN protocol, Bundle Protocol (BP), allows for standard networked communications in a store-and-forward manner.

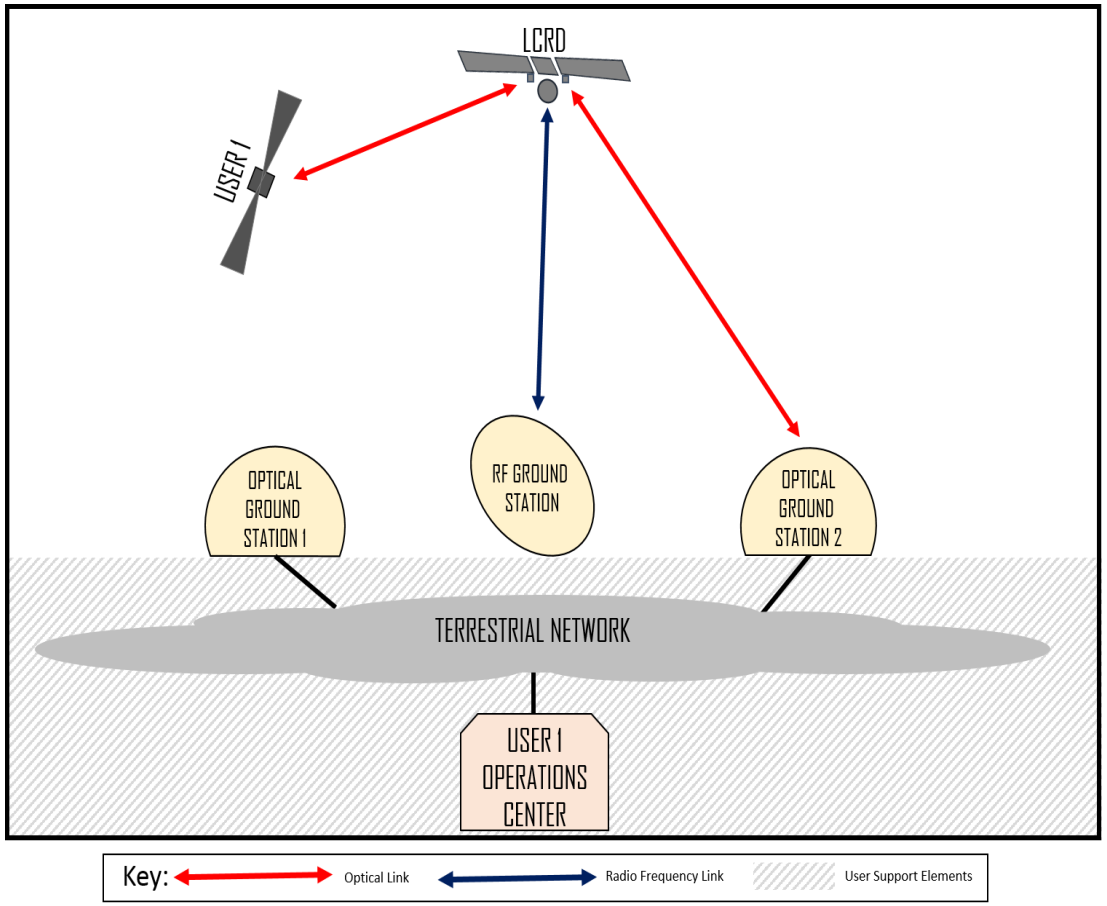
Muxing and Switching



- Muxing and switching on the relay also allows for ops concepts in which data can be relayed with another spacecraft while each spacecraft also communicates with its earthbased operations center via the RF trunkline
- Critical realtime forward link traffic could be carried up the RF trunkline and muxed on the relay with other data received at the relay from the optical trunkline

Conclusion

- The concepts described in this paper that do not require changes to the LCRD flight payload will be demonstrated
- The system will be available to demonstrate different options to inform the development of specifications for the future operational systems
- LCRD will demonstrate how the combination of both RF and optical trunklines allows the full potential of optical communications user links to be realized



Acronyms

BP - Bundle Protocol

DTE - Direct to Earth

DTN - Disruption/Delay Tolerant Network

EDRS - The European Data Relay System

Gbps - Gigabit per Second

LCRD - Laser Communications Relay Demonstration

LLCD - Lunar Laser Communications Demonstration

RF - Radio Frequency

SGL - Space to Ground Link

SWaP - Size, Weight, and Power

TDRSS - Tracking and Data Relay Satellite System