A Communications Network for Cislunar Operations

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Cislunar Possibilities

• International Space Station: science laboratory, stepping stone to further exploration.

• Constellation studies:
  – Up to five 28-day extended-stay missions at rim of Shackleton Crater, South Pole.
    • Study assumed at least one lunar relay satellite in orbit.

• Newest NASA concept: Outpost at EML-2.
  – Gateway to near-lunar space, asteroids, Mars and its moons. Astronomy, telerobotics, vehicle assembly.

• Surface ops: mining, drilling for water (RESOLVE).
EML-2 Outpost

David A. Kring / LPI-JSC Center for Lunar Science and Exploration
Strawman Lunar Operations

How will we communicate with all these sites?
Communication opportunities are scheduled, based on orbit dynamics and operations plans.

Transmission and reception episodes are individually configured, started, and ended by command. S/C to ground.

Reliability over interplanetary links is by management: on loss of data, command retransmission.

More recently – MER, Phoenix – we have had managed forwarding through a relay point: TM and some TC via Odyssey and MRO.
What’s Wrong With That?

• This mission communications model has worked fine for over forty years; we’ve done a lot of good science.

• But the status quo is:
  – Labor-intensive
    • Communication operations cost is a large fraction of the budget for each mission.
    • Risk of human error mandates mitigations that further increase cost.
  – Program-limiting
    • Cost and risk increase with the number of links between communicating entities.
    • As cross-links among spacecraft become more common (e.g., cislunar operations), cost and risk increases are non-linear with increase in the number of spacecraft.
Lunar Manned Mission Profile

Earth orbiting vehicles

Earth orbiting Relay satellites

Transit/Lagrange vehicles

Lunar comm relay

Lunar orbiting vehicle

Lunar ascent/descent vehicle

Lunar surface station

Lunar robotics

Mission control facilities

MCCs

Other ground facilities

Global Networks

Agencies:

Primary – Nominal
Secondary – Nominal
Backup/alternate
High rate
Med rate
Low rate
Optional – Note 1

Note 1 – Session data from other facilities may or may not be required to go through MCC “gateway”. Architecture supports both options.
An Alternative

- The **Internet** is very widely used on Earth, not only for commerce and social networking but also for science investigations and engineering operations.

- So why not use it for cislunar operations and interplanetary science missions too?
  - Minimize cost (automation, COTS).
  - Minimize risk (huge installed base).
It Works Fine in Near-Earth Orbit

- **Space Communication Protocol Standards (SCPS)**
  - TCP options that improve performance on satellite links, where data loss is more often due to corruption than to congestion
  - International standard (CCSDS and ISO as well as DoD)

- **Operating Missions as Nodes on the Internet (OMNI)**
  - UoSAT-12, an HTTP server in orbit
  - CHIPSat, used Internet protocols on all communication links
  - CANDOS on STS-107, used mobile IP

- IP stack would also work well in **surface networks on other planetary bodies.**
So What’s the Problem?

- Interplanetary space is a qualitatively different environment.
  - Internet, near-Earth, and planetary surface networks are all characterized by:
    - Very short distances between communicating nodes, therefore very brief signal propagation delays (up to a few hundred milliseconds).
    - Continuous end-to-end connectivity. A network partition is treated as an anomaly and allowed to terminate communication.
  - Any network spanning interplanetary space would be characterized by:
    - Long distances between communicating nodes, lengthy signal propagation delays (e.g., 1300 milliseconds from Earth to the Moon, 4-20 minutes from Earth to Mars).
    - Routine network partitioning due to lapses in connectivity on one or more links of the end-to-end path.
Ruling Out the Internet Architecture

• TCP isn’t suitable, for a variety of reasons.
• There’s no alternative Internet standard for reliable transmission that would work over interplanetary links.
• So no standards for flow control and congestion control.
• None of the standard routing protocols would work.
  – BGP relies on TCP. Others rely on timers that won’t work right.
  – Transient network partitioning would be interpreted as topology changes, an error.
• And no COTS routers would work.
  – Interruption of outbound link must cause outbound traffic to be queued rather than discarded.
• All that’s left is UDP/IP with static routing: just a less bit-efficient packaging alternative to raw CCSDS packets.
Delay-Tolerant Networking (DTN)

- An overlay network.
  - DTN “bundle protocol” (BP) is to IP as IP is to Ethernet.
  - A TCP connection within an IP-based network may be one “link” of a DTN end-to-end data path; a deep-space R/F transmission may be another.

- Reliability is achieved by retransmission between relay points within the network, not end-to-end retransmission.

- Route computation may have temporal as well as topological elements, e.g., a schedule of planned contacts.

- Forwarding at router is automatic but not necessarily immediate: store-and-forward rather than “bent pipe”.

- DOS attacks contained: reciprocal inter-node suspicion.
DTN Operations in space

- Mars relay orbiter 1
- LTP over expedited Proximity-1
- LTP over space link (AOS or TM/TC)
- Lunar relay orbiter
- LTP over expedited Proximity-1
- LTP over space link (AOS or TM/TC)
- Mars relay orbiter 2
- TCP/IP over wireless LAN
- TCP/IP over wireless LAN
- BP over multiple links

- Earth
- Internet
- Workstation
- Antenna complex
- Mars
- Rover
- Landers
- Lunar relay orbiter
- TCP/IP over wireless LAN
- Orbiters
- Mars relay orbiter 1
- LTP over expedited Proximity-1
- LTP over space link (AOS or TM/TC)

CFDP file transfer, AMS message exchange
DTN for Mission Communications

• Automatic **relay** operations.
  – Retain data until outbound link is available.
  – Then transmit until link is no longer available.
• Fine-grained **routing**: automatic selection of (possibly parallel) links to transmit over, based on the final destination of the data.
• Automatic selection of data to transmit, based on mission-specified **priority**.
• Automatic **retransmission** of lost or corrupted data.
• Automatic **aggregation** of data into blocks, to limit acknowledgment traffic.
• **Custodial forwarding**, for early release of retransmission buffer space.
• Automatic **congestion control**, based on rate management.
• Automatic **data aging and purging** based on bundle’s “time to live”.
• Optional status reports for detailed **tracing and data accounting**.
• Support for **file transfer, message exchange, multi-point delivery**.
• Support for **security**: authentication, encryption.
DTN for Cislunar Operations

EML-1

EML-2

Mining and drilling

Shackleton Crater base
The EML-1 relay can be used for communication among the mining sites on the “near side” – and with the Shackleton Crater site – as well as linking with Earth. So the EML-1 node and the Shackleton node offer alternative data paths to Earth.

The EML-2 outpost similarly enables communication among the “far side” sites and with Shackleton, and from there back to Earth.

EML-1 altitude from lunar surface is 56,000 km; EML-2 altitude is 67,000 km. Halo orbit at EML-2 has angular extent larger than the moon’s disk as seen from Earth, so direct-to-Earth links from EML-2 should be possible, offering another alternative data path to Earth.
How Will It Be Implemented?

International Space Flight Community

Interagency Operations Advisory Group
Chartered SISG to recommend an approach for space Internetworking

Space Internetworking Strategy Group

NASA, ESA, CNES, DLR, JAXA....

Increasing mission complexity

DARPA
DTN Research Group (formed within the Internet Research Task Force)

Designed protocols that let networks tolerate link disruptions and long delays

DTN for resource-limited systems

DTN Protocol Specifications

ION

Implementation

Solar System Internet

Recommends DTN
First Stage of Deploying the SSI
SSI Architecture: Operations Model
SSI Architecture: Coordination Model
Protocols

• Bundle Protocol (RFC 5050)
  – Delay-tolerant forwarding, quality of service, congestion control, tracing and data accounting
  – Data aging and purging
  – Route computation based on contact graphs
• Licklider Transmission Protocol (RFC 5326)
  – Delay-tolerant retransmission of lost data
• Bundle Security Protocol (RFC 6257)
  – Authentication, encryption, integrity protection
• CCSDS File Delivery Protocol (727.0-B-4)
  – Delay-tolerant file transfer
• CCSDS Asynchronous Message Service (735.1-B-1)
  – Delay-tolerant message middleware
Technology

• Interplanetary Overlay Network (ION) implementation of the DTN protocols:
  – Designed to be suitable for use in flight computers.
    • Small footprint, efficient use of processor
    • Private management of a fixed memory allocation
    • Ported to real-time operating systems (VxWorks, RTEMS) as well as Linux, OS/X, FreeBSD, Solaris, Windows
  – Demonstrated on a flying spacecraft (EPOXI) in 2008, acting as an in-space router 15 million miles from Earth.
  – Configuration-managed by the NASA ION Working Group since 2009.
  – Freely available to all national space agencies and commercial space flight providers: http://sourceforge.net/projects/ion-dtn/.
Summary

- Reliable and efficient communications will be critical to the success of commercial flight operations in cislunar space.
- The Internet is not well-suited to meeting this requirement. But the Delay-Tolerant Networking (DTN) architecture is.
- The DTN protocols are well-documented and implementations are mature.
- We think DTN will be ready to support low-cost, low-risk cislunar networking by the time the vehicles are in place.