Lunar Networking

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Networks Enable Lunar Exploration

Data Challenges

- Higher lunar data volume
  - 10-100x
- Uneven comms coverage
  - Mission-specific relays
  - No global lunar coverage
  - Direct-to-Earth requires well-resourced platforms

Data Solutions

- Shared Infrastructure
  - Reduce per-mission costs
  - Broader coverage
  - More & faster paths to Earth
- Networking Semantics
  - Resilient path diversity
  - Data security & scalability
Networking Past GEO is a Challenge

• “Space networks” operate around LEO
  • Very expensive – thousands of spacecraft
  • Terrestrial network technology fails at/near LEO
  • User lag unacceptable at GEO

• Harder challenges for Lunar networks
  • Luna is ~9x further away than GEO
  • Requires new networking technology
  • Requires new governance/usage models
What is a Lunar Network?

• A network **is**:  
  • The emergent behavior of many cooperating networking devices.  
    • Routers, switches, hubs, etc…  
    • We do not “purchase” a network…  
    • We purchase networking devices.

• A network **is not** a point-to-point link  
  • Spacecraft have multiple terminals  
  • Mesh, Directional RF, Optical

• A network **is not** a single relay  
  • Relays have different orbits, compatibilities, services, administration, and performance characteristics

Fig. 1. LunaNet Architecture
Unifying Links

• Networks unify communications links
  - There is no “magic radio/terminal” to rule them all
  - Spacecraft may have multiple (and different) “links”
    ▪ Mesh, Directional RF, Optical.
    ▪ Different personalities. Different security/performance.
  - Vendor solutions do not always interoperate
    ▪ Even when implementing same “standards”
  - Environments can be challenged and contested
    ▪ Planned and unplanned disruptions
    ▪ (Un)planned disruptions.

• A Unifying Lunar Network
  - Simplifies application development.
  - Provides traffic engineering & management services.
  - Has interoperable, standardized **syntactic** behavior.
  - Has consistent, configurable **semantic** behavior.

• Space Networking…
  - Allows for targeted capabilities (Good)
  - Provides path diversity and resilience (Good)
  - Requires coordination (Hard)
  - Must scale over the years (Hard)
  - Requires sharing from the start (Really Hard)
Network Systems Engineering

Network engineering is more than addressing technology gaps

- **What are the components of an operational space network?**
  - Identify technology gaps
  - Discuss data and control flows
  - Understand contributions of vendors\standards
  - Recommend on next steps for standards activity
  - Avoid local minima (aka… the easy way out)

- **Three perspectives from APL supporting:**
  - CCSDS (Peter Shames)
  - IOAG (Jim Schier)
  - IPNSIG (Vint Cerf, strategy working group)

- **Observations**
  - Diversity is our friend
  - Need to track advancements from industry and others
  - Converging on proper terminology important

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A CCSDS Perspective
The Three-Phased Solar System Internet

• The CCSDS is defining “stages of evolution” of the SSI concept
  - Stages 1, 2a, 2b, and 3
    - **Stage 1**: Mission Functionality
      o Bespoke solutions.
      o Test individual technologies.
    - **Stage 2**: Internetwork Functionality
      o 2a: Manually (possibly mission-specific) management
      o 2b: Interoperable configuration and management.
      • More emphasis here on security
    - **Stage 3**: Advanced Functionality
      o The network we want.
      o Peering, networking, authorization agreements.

“End-to-End” – Forward, SSI Stage 2 ESLT
(no security shown)

An IOAG Perspective
Lunar governance and operations

• How do we govern?
  - What are governance structures and approaches?
  - What organizations should participate in creating these?
  - How are lunar networks same/different from the Internet?
  - What are steps to implementation

• Guiding Principles
  - Open architecture
  - Interoperability with open international standards
  - Scalable and dynamic
  - Secure and resilient
  - Consensus-based decisions
  - Open, inclusive, transparent peer participation
  - Extensible across the solar system
**An IPNSIG Perspective**


- **Key properties of an SSI**
  - Collaboration
  - Global Standards
  - Stability
  - Democracy
  - Affordability
  - Expandability
  - Security

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Incentives and challenges for cooperation</th>
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<tbody>
<tr>
<td><strong>Governments</strong></td>
<td><strong>Private actors</strong></td>
</tr>
<tr>
<td>Ensure access to technologies and services</td>
<td>Access to know-how, resources, and financial support</td>
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<tr>
<td>Support a sustainable model for space exploration</td>
<td>Gain credibility, validate their capabilities</td>
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<tr>
<td>Foster domestic industry growth and cooperation</td>
<td>Create potential revenue streams</td>
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</table>

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<th><strong>Governments</strong></th>
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<td>Mutual understanding of expectations and goals</td>
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<tr>
<td>Establishment of appropriate cost and risk-sharing schemes</td>
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<tr>
<td>Changes in government priorities and funding</td>
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<tr>
<td>Commercial viability and profitability</td>
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</table>
Identified Technology Gaps
How to standardize those for everyone

• **Store and Forward Data Exchange**
  - Do **not** assume a path exists all at once.
  - Do **not** assume endpoints remember things for you.
  - Do **not** retransmit from the source. Inchworm through the network.
  - Do **store** data for milliseconds... or days.
  - Do **carry** all data and metadata in the same message.

• **End-to-end Security**
  - Do **not** rely solely on physical layer security.
  - Do **secure** different parts of a packet separately.
  - Do **optimize** for security at rest.

• **Autonomy as Network Management**
  - Do **not** assume an operator in the loop.
  - Do **incorporate** autonomy and automation. Operator “on” the loop.
  - Do **push** information proactively into the network.
  - Do **be compatible** with terrestrial management approaches.

• **Routing**
  - Do **adjust** to time-variant topologies.
Where do we standardize things?

Two significant standards organizations

**Internet Standards**
- **IETF**
  - **Areas**
    - Real-Time Apps
    - Internetworking
    - Ops/Mgmt
    - Routing
    - Security
    - Transport

  - Expertise in Internet, ISPs, IoT, MANET.
  - ~1500 attendees meet 3x year
  - Open to anyone

**Space Standards**
- **CCSDS**
  - **Areas**
    - Systems Engineering
    - Missions Ops/Mgmt
    - Cross-Support
    - Spacecraft Onboard
    - Space Link
    - Space Internetworking

  - Expertise in space mission development and operations.
  - 100s of attendees meet 2x year
  - Requires space agency Sponsorship
We must mix cultures, experiences, and expertise.

A space internet is a combination of space expertise and internet expertise.
IETF DTNWG – How to Participate

• Review online materials
  • DTNWG has a “homepage”.
  • https://datatracker.ietf.org/wg/dtn/documents/

• Watch meetings on YouTube
  • Search for “IETF # DTN” on YouTube.
  • For example, “IETF 115 DTN”
  • https://www.youtube.com/watch?v=kqA-19a_XQY

• Join the mailing list
  • Mailing list homepage.
  • https://www.ietf.org/mailman/listinfo/dtn
  • Subscribe or view archive

• Attend a meeting
  • https://ietf.org
  • Virtual attendance is supported!
IETF Standards

APL is authoring networking standards and infusing them into devices

Internet Engineering Task Force (IETF)
Request for Comments: 9172
Category: Standards Track
ISSN: 2070-1721

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Bundle Protocol Version 7

Abstract

This document presents a specification for the Bundle Protocol, adapted from the experimental Bundle Protocol specification developed by the Delay-Tolerant Networking Research Group of the Internet Research Task Force and documented in RFC 5058.

Primary Block | Extension Block 1 | Extension Block 2 | Extension Block 3 | Payload Block
---|---|---|---|---
Required Block - Identifies the bundle - Specifies processing options - Adds routing information
Optional Blocks - Encodes processing options for the bundle - Carries annotative payload information - Provides information for downstream nodes
Required Blocks - Includes user payload - May represent a fragment of a user payload - May represent other encapsulated data

Internet Engineering Task Force (IETF)
Request for Comments: 9172
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January 2022

Bundle Protocol Security (BPSec)

This document defines a security protocol providing data integrity and confidentiality services for the Bundle Protocol (BP).
Spotlight Technology: BPv7 (RFC9171)

• What is BPv7?
  - A Transport Protocol for the UN
  - Three main features
    ▪ Dynamic extension block mechanism
    ▪ Standardized store/forward
    ▪ More flexible naming scheme

• Benefits
  - Persistent node storage
    ▪ To support TVR
  - Custodial Transfer
    ▪ Do not start over from the beginning
  - Dynamic Annotation
    ▪ In-band security and policy
  - Efficient Data Transmission
    ▪ Less control traffic
    ▪ Data aggregation
    ▪ Data abstraction
      ○ BP over LTP, TCP, UDP, QUIC, IP, etc…
Spotlight Technology: BPSec (RFC9172)

• What is BPSec?
  - Security extensions for BPv7
  - Block-by-block security
    ▪ Not whole-PDU security

• Benefits
  - Multiple annotations in a “bundle” may be secured separately.
    ▪ Encrypt a payload
    ▪ Sign a header
  - Allows secured block manipulation
    ▪ Adding a secured block to a bundle at a waypoint.
    ▪ Building overlapping security tunnels.
  - Possibly useful for data aggregation
    ▪ Aggregate data flows into BP extension blocks
    ▪ Secure blocks differently
      ▪ Different cipher suites, keys
    ▪ Provides aggregation plus per-flow security.
  - Provides security-at-rest
    ▪ When bundles are in store/forward state
Other IETF Work

Time-Variant Routing

• How to create new working groups
  • (Often) Birds of a Feather (BOF) Meetings
    • Document problems to be solved.
    • Gauge community expertise and interest.

• IETF 115 BOF
  • Time-Variant Routing (TVR)
    • 135 attendees. ~70 for (~5 against) creating a new working group.
  • Recording:
    • https://www.youtube.com/watch?v=uc4pwwj6bR0

• Standardize ways to account for known link changes in a network
  • When links come and go.
  • Important consideration for interplanetary spacecraft.
  • Also important for terrestrial use cases
    • Eco-computing. Extending sensor life. Lower utility costs.
Spotlight Technology: CGR/SABR

• What is CGR/SABR?
  - Contact Graph Routing (CGR)
  - SABR (Schedule-Aware Bundle Routing)
  - Break routing into 3 phases
    - Planning
    - Routing
    - Forwarding

• Benefits
  - Allows topology data from multiple sources
    - Authoritative: Confirmed pass in 5 minutes
    - Predictive: Expect a contact around now
    - Opportunistic: An unexpected active link
  - Prepare for a pass in advance
    - Even when negotiating passes machine-to-machine.

IETF Brief History of DTN
https://youtu.be/xSDxJGdjjw98?t=889
IPNSIG Academy
Standardization of DTN in the IETF

IPNSIG Academy Talk #8
‘IETF Standardization Efforts’

IPNSIG Academy

December 7 2022

IPNSIG Academy – Program for 2022:
1. Yosuke Kaneko
2. Vinton G. Cerf
3. Scott Burleigh
4. Oscar Garcia
5. Lara Suzuki
6. Dave Israel
7. David Gomez Otero
8. Ed Birrane
9. Keith Scott
10. Laura DeNardis
11. Scott Pace
12. “IPNSIG Workshop”

100+ years vision
DTN Overview
SSI Architecture study
DTN Projects Work
DTN live demonstration
NASA Luna Net Overview
ESA Moonlight Overview
IETF standardization efforts
CCSDS standardization efforts
Internet Governance issues
Space Polley, perspective on IPN governance
Architecture and Governance of IPN

https://isoc.live/16141/