JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

11100 Johns Hopkins Road
Laurel, MD 20723-6099

Lunar Networking

Edward J. Birrane, Ph.D.
Johns Hopkins University, Applied Physics Laboratory (JHU/APL)
Edward.Birrane@jhuapl.edu
(W) 443-778-7423

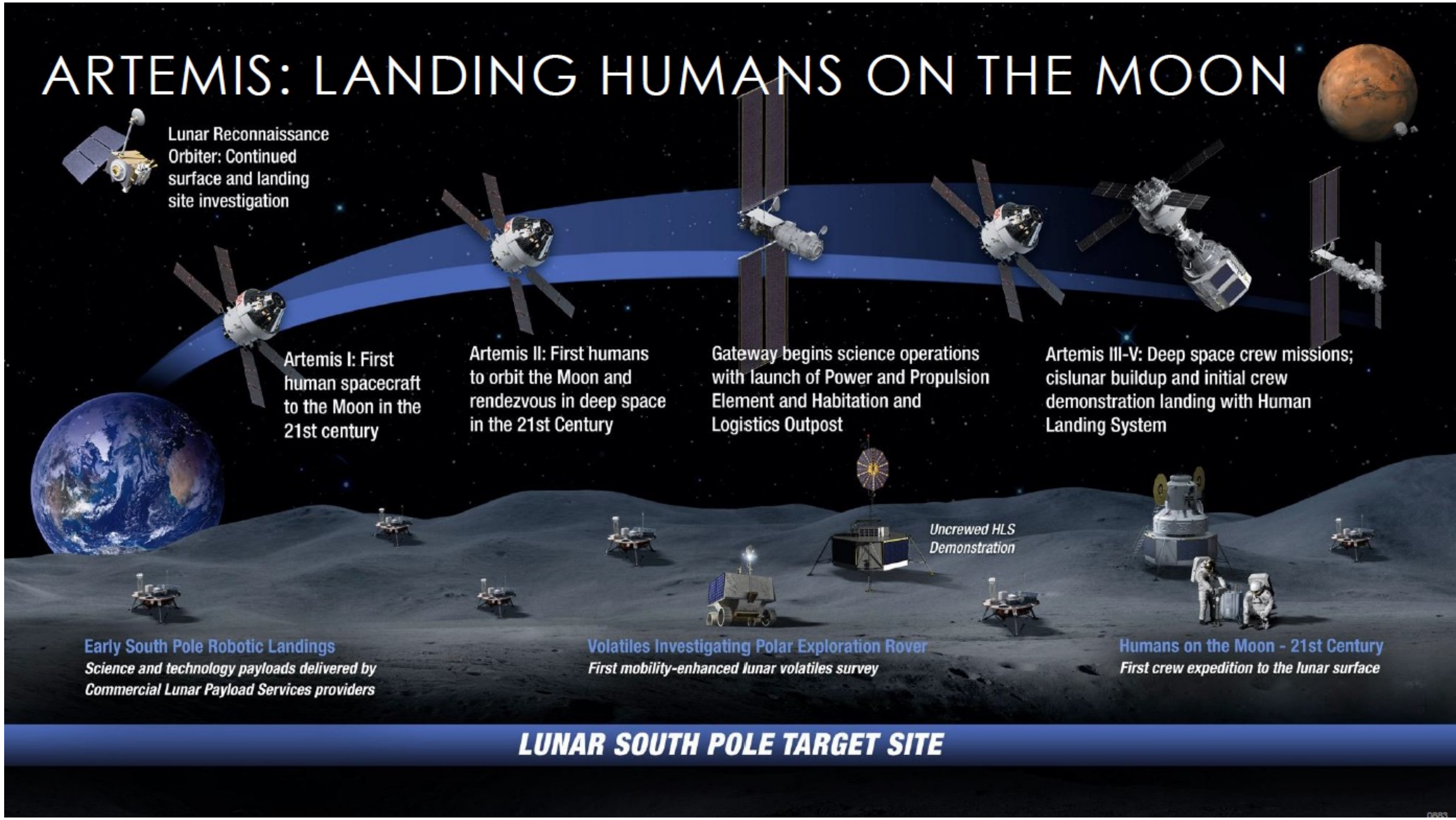
Networks Enable Lunar Exploration

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

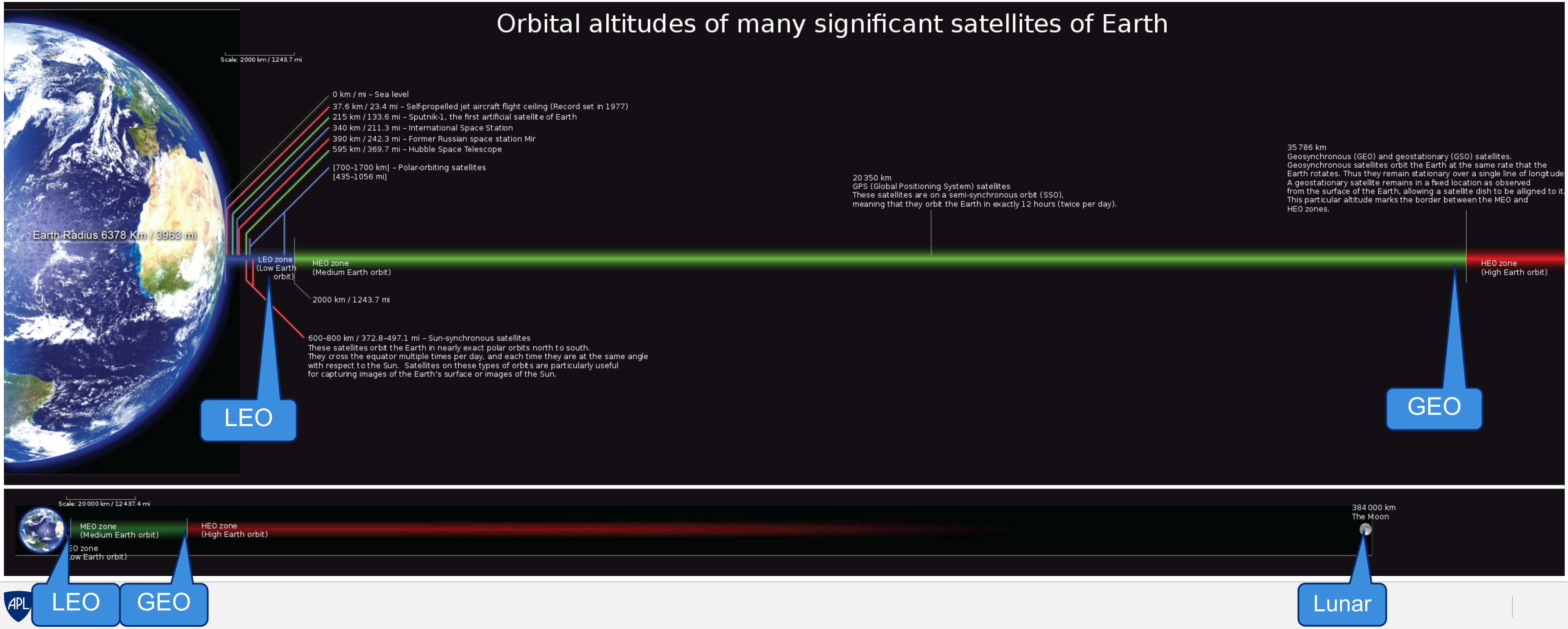
Data Solutions

- **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



APL

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

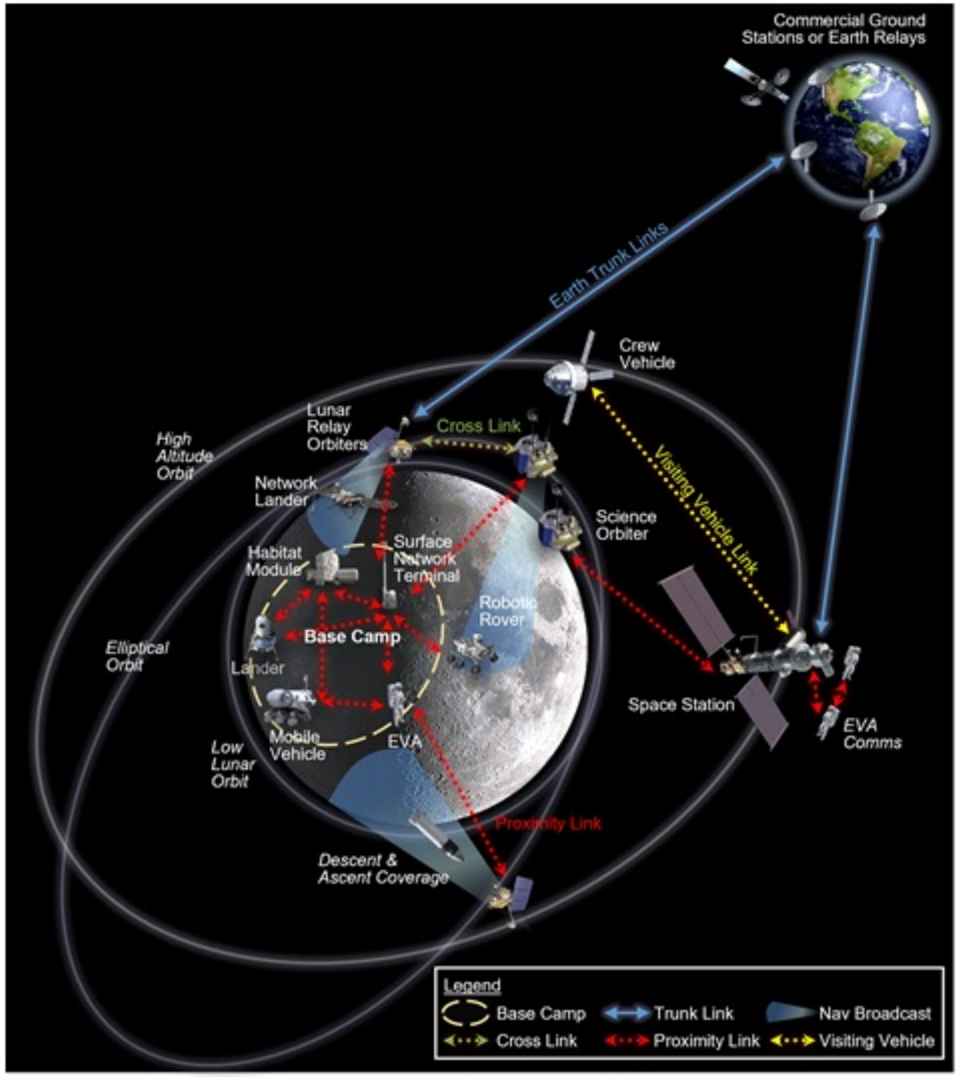
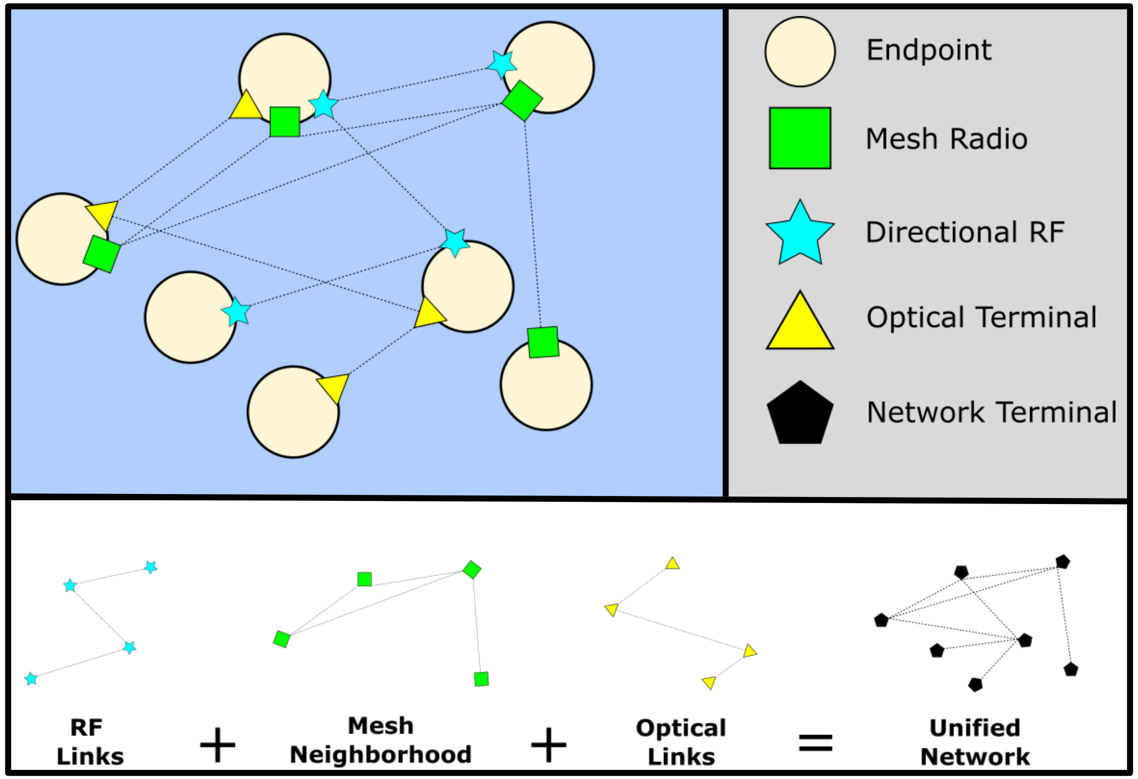


Fig. 1. LunaNet Architecture

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.

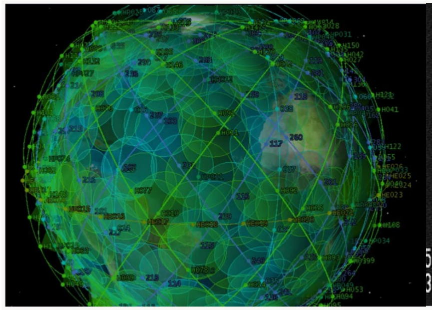


- Space Networking…
  - Allows for targeted capabilities (Good)
  - Provides path diversity and resilience (Good)
  - Requires coordination (Hard)
  - Must scale over the years (Hard)
  - Requires sharing from the start (Really Hard)

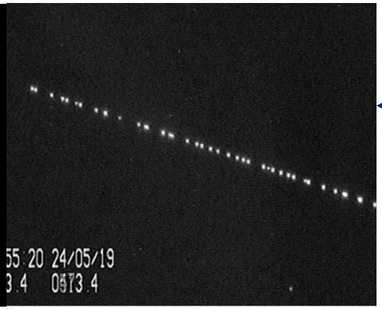
Network Systems Engineering

Network engineering is more than addressing technology gaps

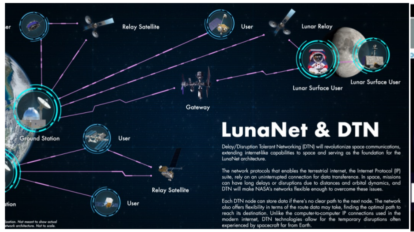
- **What are the components of an operational space network?**
  - Identify technology gaps
  - Discuss data and control flows
  - Understand contributions of vendors\standards
  - Recommend on next steps for standards activity
  - Avoid local minima (aka… the easy way out)
- **Three perspectives from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

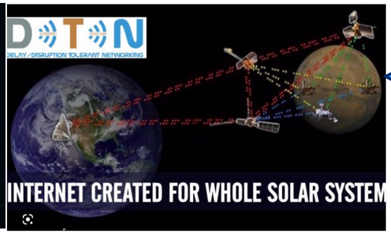


The Space Development Agency was created in 2019 to design a National Defense Space Architecture in low Earth orbit. Credit: SDA

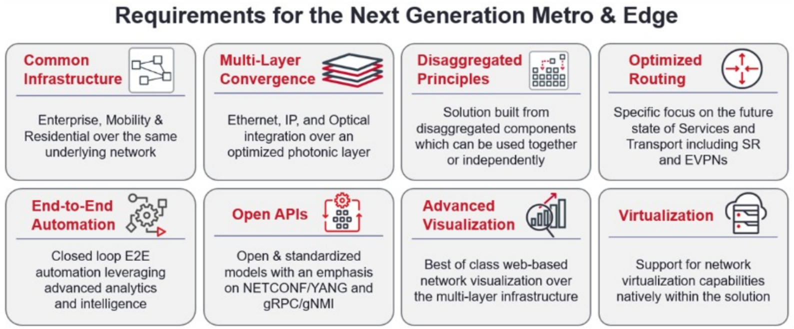


There will be links





We have standards



https://www.ciena.com/insights/articles/how-service-providers-can-win-by-owning-the-edge.html

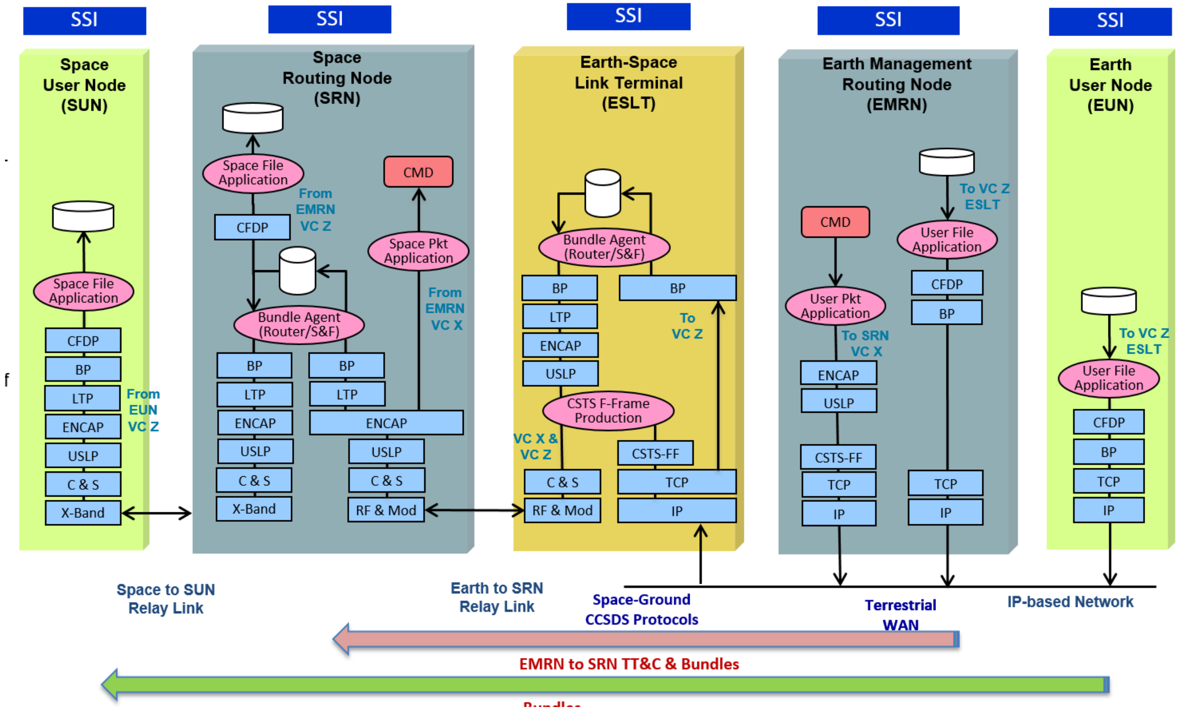
We need much more

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
      - Bespoke solutions.
      - Test individual technologies.
    - **Stage 2**: Internetwork Functionality
      - 2a: Manually (possibly mission-specific) management
      - 2b: Interoperable configuration and management.
        - More emphasis here on security
    - **Stage 3**: Advanced Functionality
      - The network we want.
      - Peering, networking, authorization agreements.

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

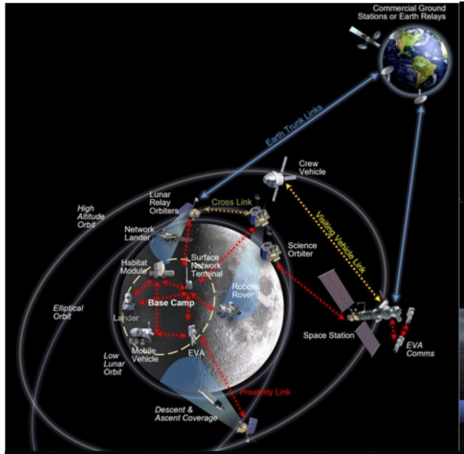


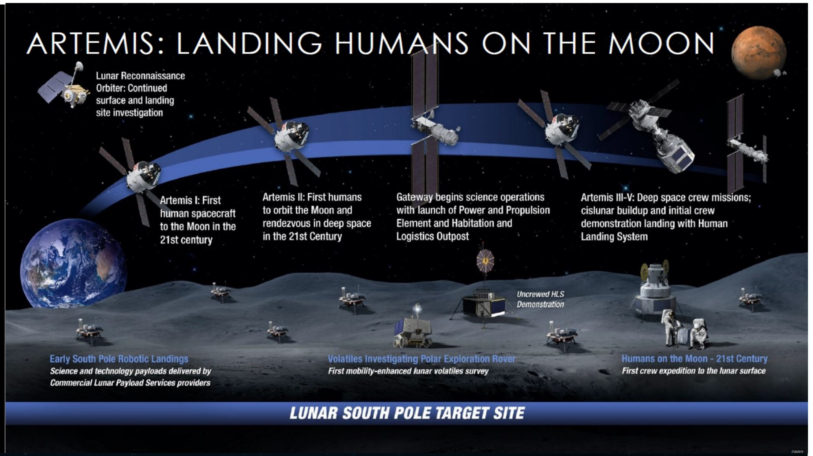
Source: CCSDS, “Space Communications Cross Support Architecture Requirements”, CCSDS 901.1-M-1, dated May 2015

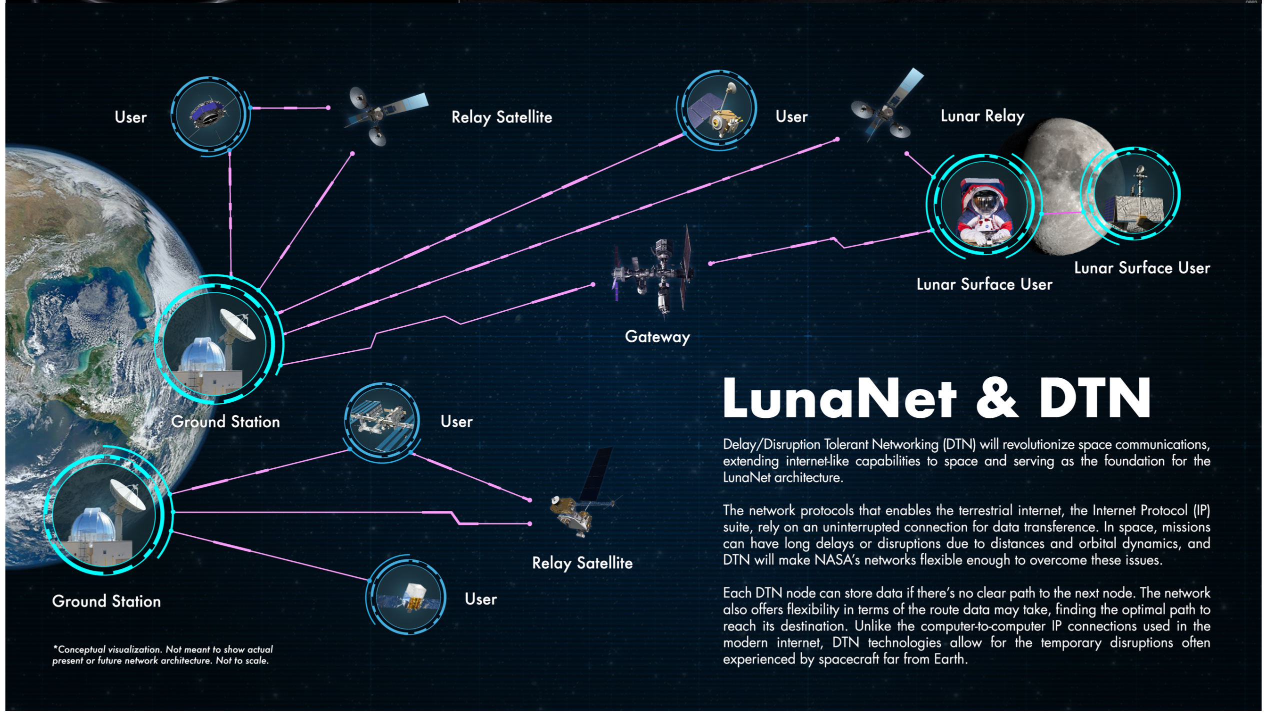
An IOAG Perspective

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

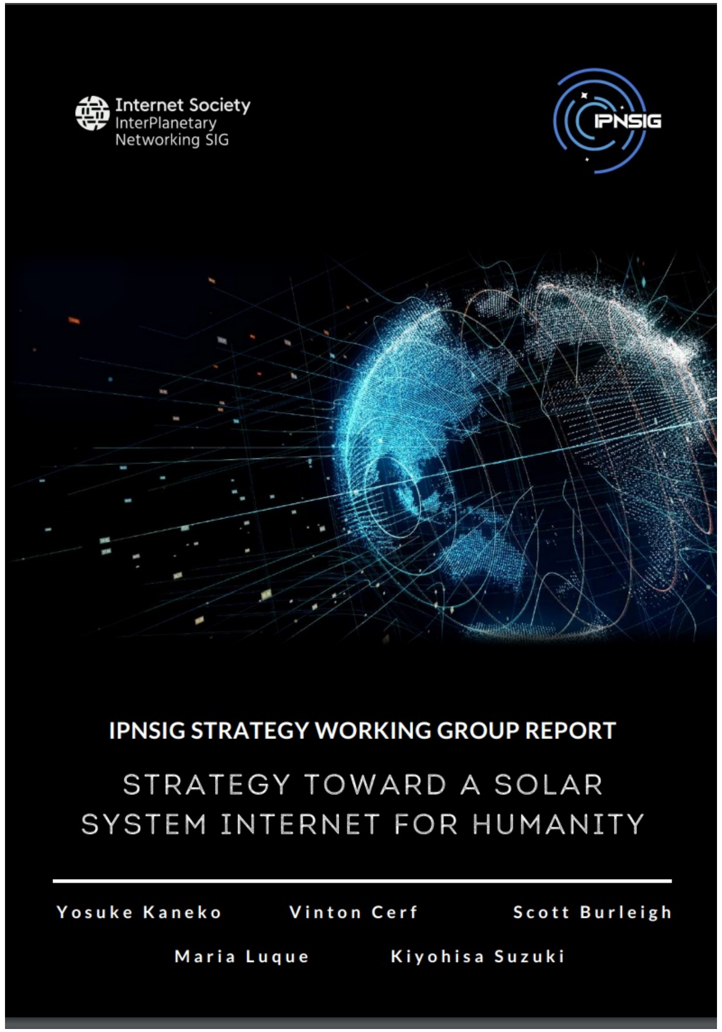
https://ipnsig.org/wp-content/uploads/2021/10/IPNSIG-SWG-REPORT-2021-3.pdf

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

Table-1 Incentives and challenges for cooperation

Incentives for cooperation (co-creation, risk-sharing, pooling & sharing)	
Governments	**Private actors**
Ensure access to technologies and services	Access to know-how, resources, and financial support
Support a sustainable model for space exploration	Gain credibility, validate their capabilities
Foster domestic industry growth and cooperation	Create potential revenue streams

Challenges to cooperation (co-creation, risk-sharing, pooling & sharing)	
Governments	**Private actors**
Mutual understanding of expectations and goals	
Establishment of appropiate cost and risk-sharing schemes	
Change in government priorities and funding	
Commercial viability and profitability	

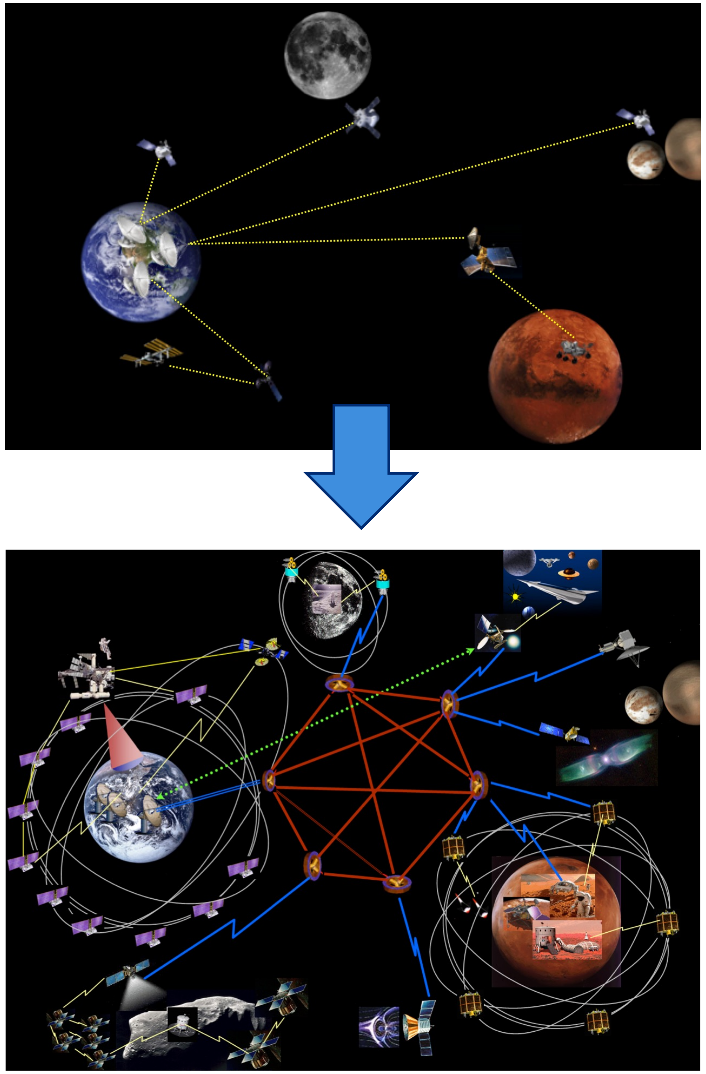


https://www.nasa.gov/directorates/heo/scan/engineering/technology/disruption_tolerant_networking_history
https://www.nasa.gov/directorates/heo/scan/engineering/technology/disruption_tolerant_networking

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

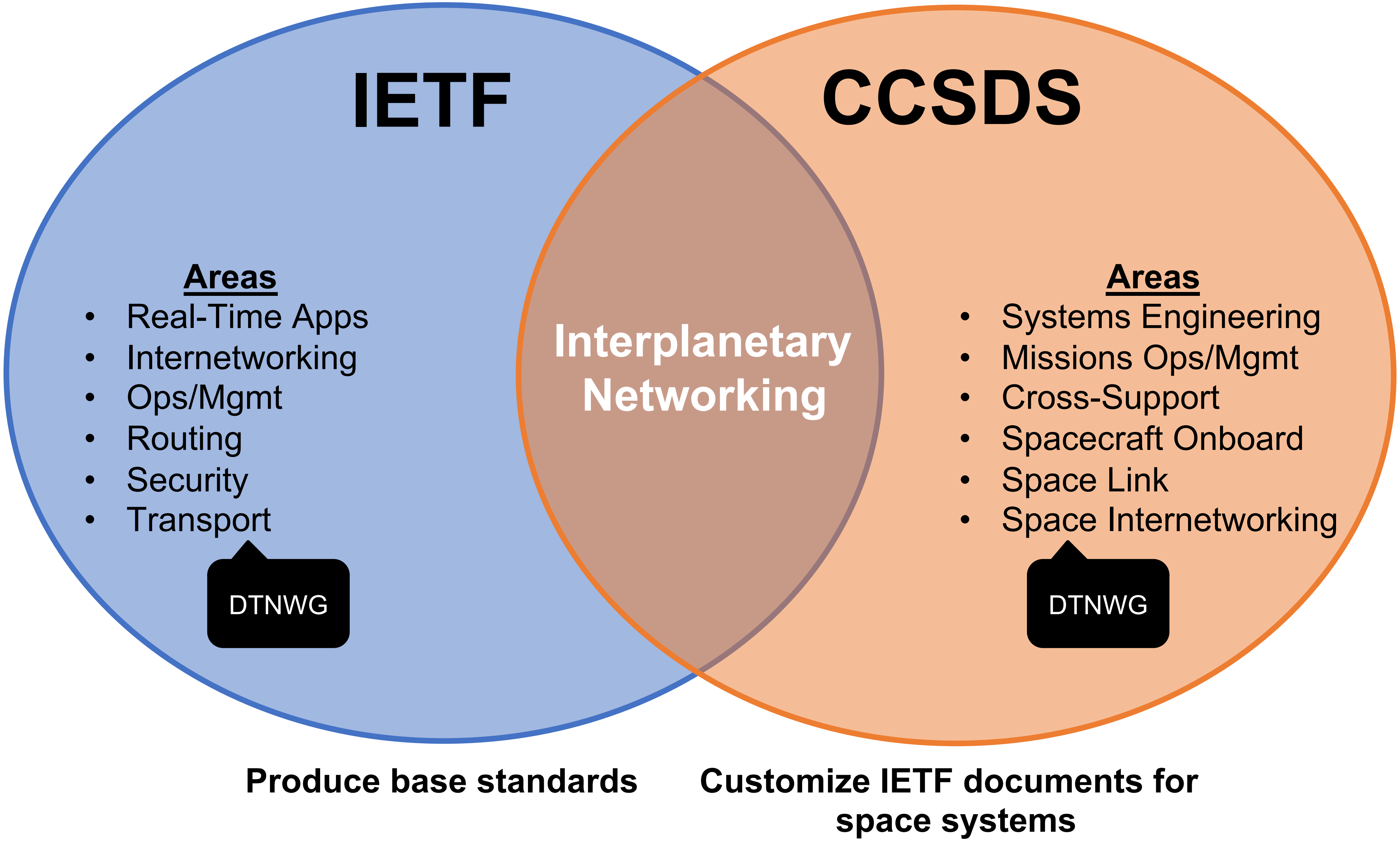
Areas

- 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

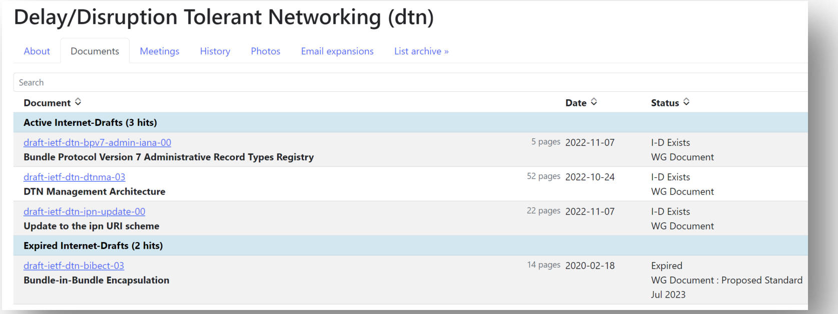
We must mix cultures, experiences, and expertise.

A space internet is a combination of space expertise and internet expertise.

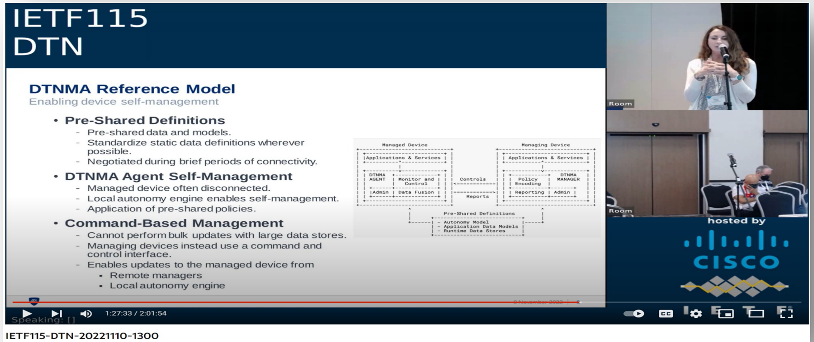


IETF DTNWG – How to Participate

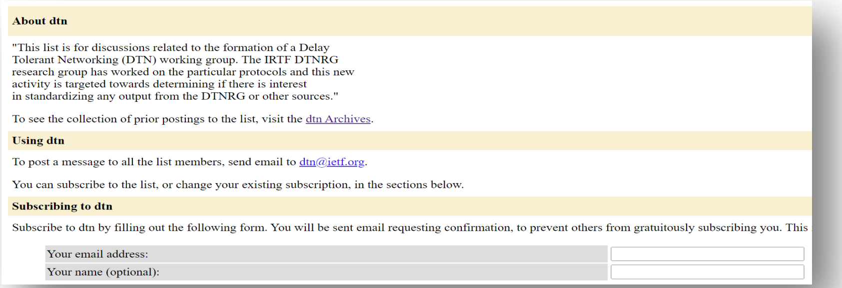
- Review online materials
  - DTNWG has a “homepage”.
  - https://datatracker.ietf.org/wg/dtn/documents/



- 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

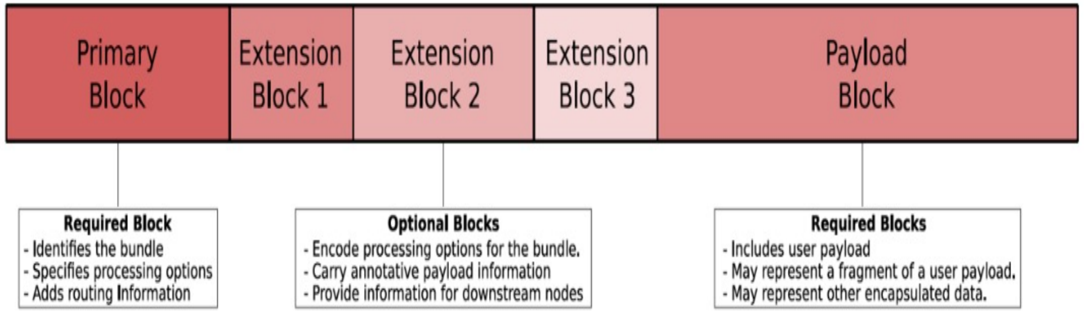


- Attend a meeting
  - https://ietf.org
  - Virtual attendance is supported!

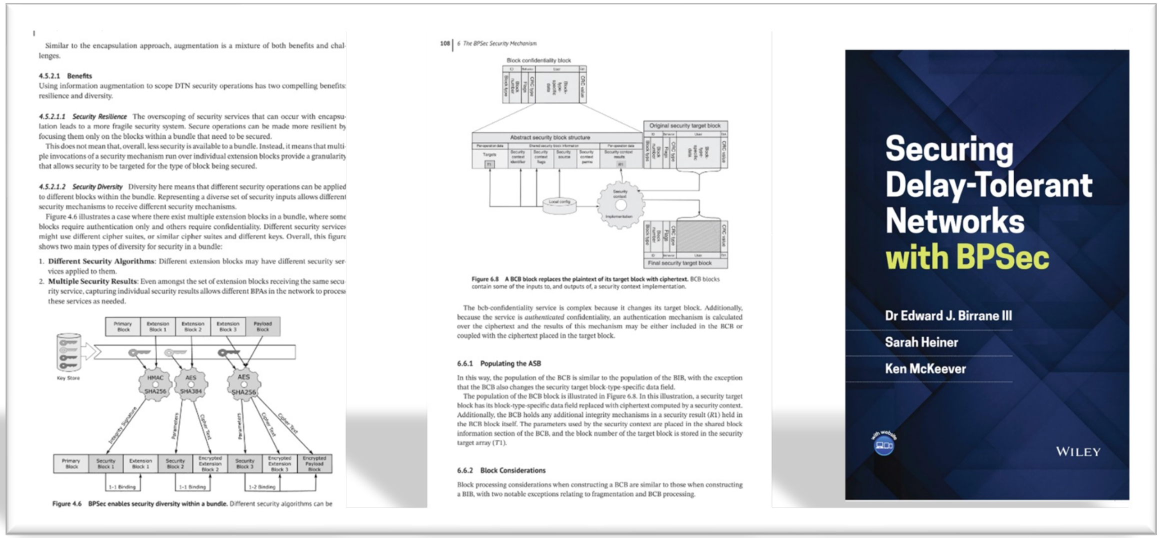
IETF Standards

APL is authoring networking standards and infusing them into devices

```
Internet Engineering Task Force (IETF)                       S. Burleigh
Request for Comments: 9171                                      IPNGROUP
Category: Standards Track                                        K. Fall
ISSN: 2070-1721                                Roland Computing Services
                                                          E. Birrane, III
                                           APL, Johns Hopkins University
                                                             January 2022

                       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 5050.
```

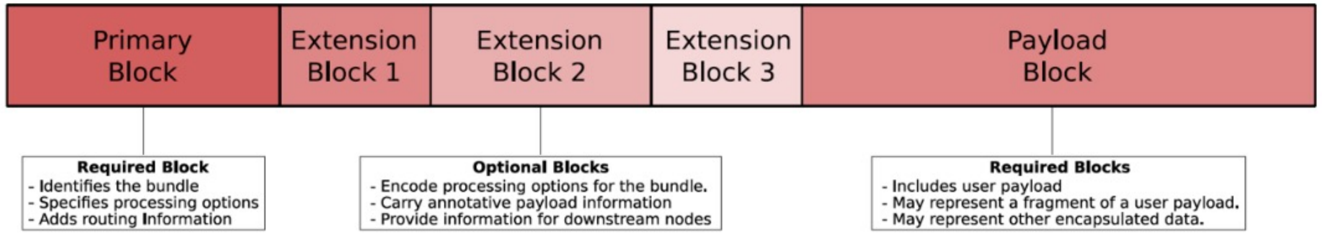


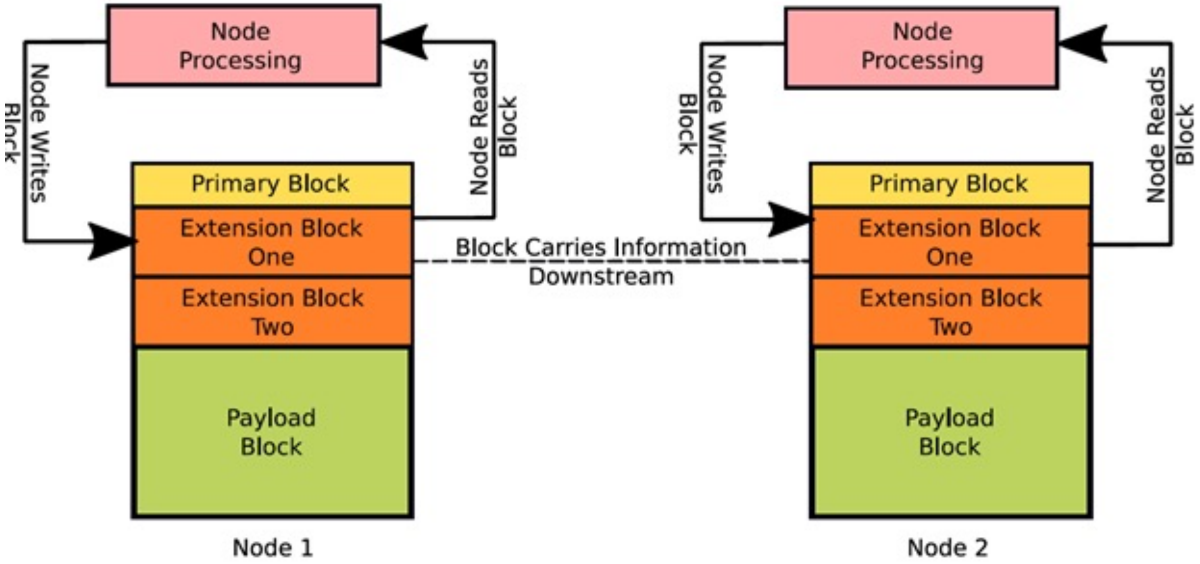

```
Internet Engineering Task Force (IETF)                  E. Birrane, III
Request for Comments: 9172                                  K. McKeever
Category: Standards Track                                       JHU/APL
ISSN: 2070-1721                                            January 2022

                  Bundle Protocol Security (BPSec)

Abstract

   This document defines a security protocol providing data integrity
   and confidentiality services for the Bundle Protocol (BP).
```



Spotlight Technology: BPv7 (RFC9171)

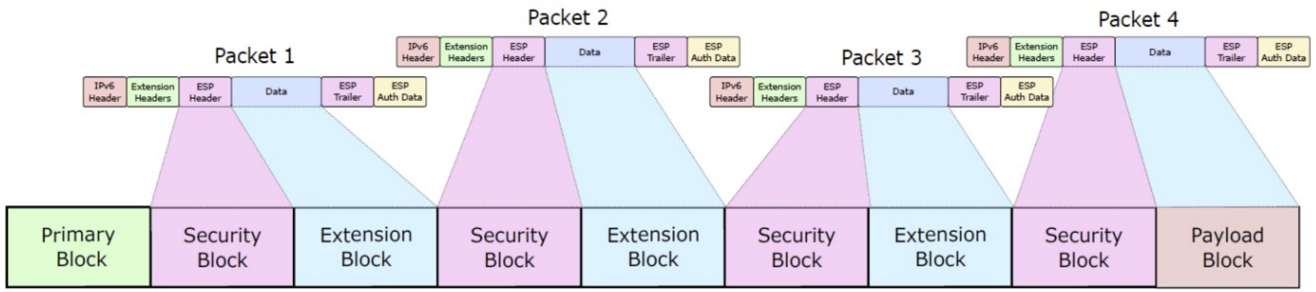
- What is BPv7?
  - A Transport Protocol for the UN
  - Three main features
    - Dynamic extension block mechanism
    - Standardized store/forward
    - More flexible naming scheme
- Benefits
  - Persistent node storage
    - To support TVR
  - Custodial Transfer
    - Do not start over from the beginning
  - Dynamic Annotation
    - In-band security and policy
  - Efficient Data Transmission
    - Less control traffic
    - Data aggregation
    - Data abstraction
      - BP over over LTP, TCP, UDP, QUIC, IP, etc…

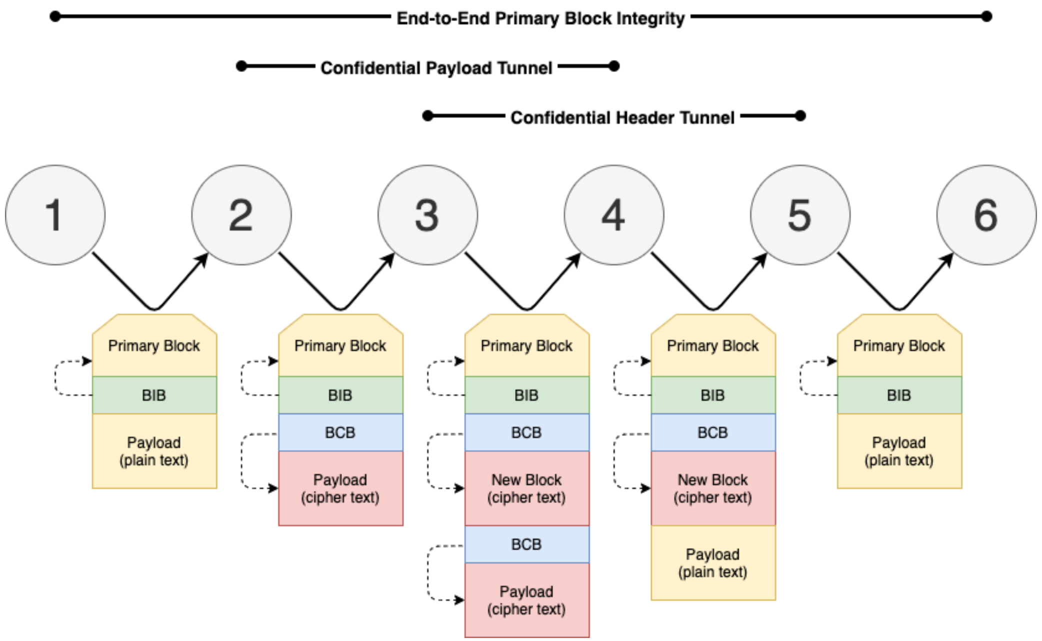




Spotlight Technology: BPSec (RFC9172)

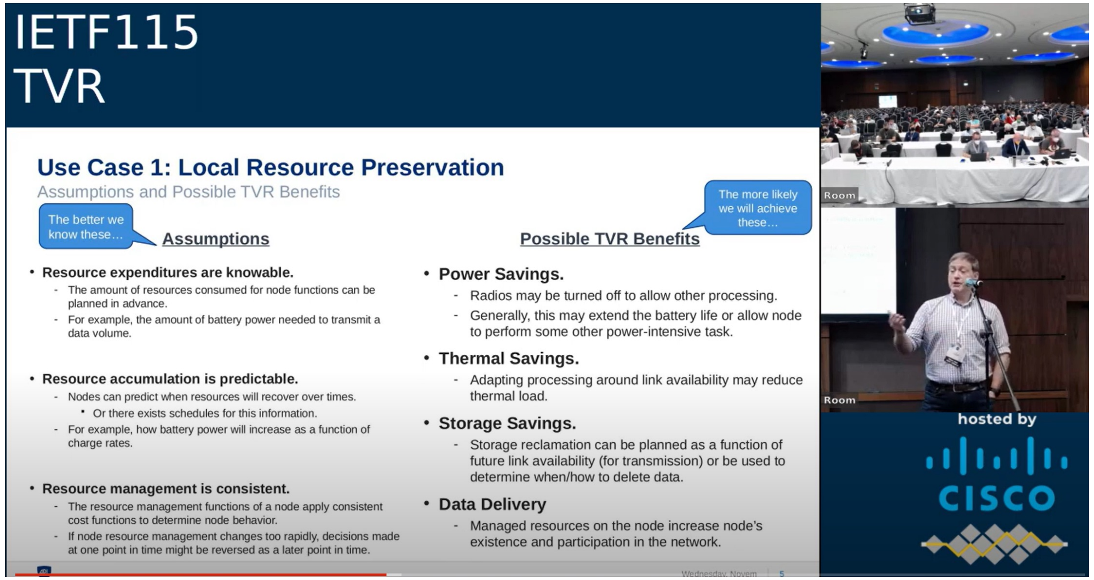
- What is BPSec?
  - Security extensions for BPv7
  - Block-by-block security
    - Not whole-PDU security
- Benefits
  - Multiple annotations in a “bundle” may be secured separately.
    - Encrypt a payload
    - Sign a header
  - Allows secured block manipulation
    - Adding a secured block to a bundle 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



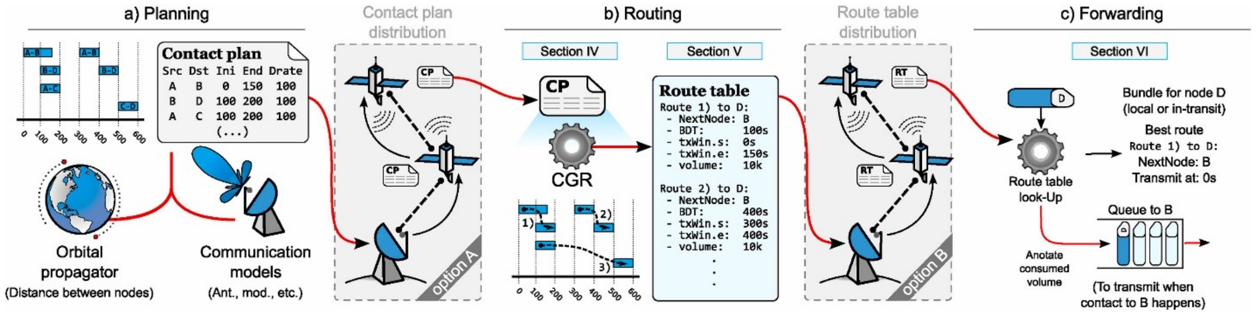
- How to create new working groups
  - (Often) Birds of a Feather (BOF) Meetings
    - Document problems to be solved.
    - Gauge community expertise and interest.

- 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.



Fraire, J. A., De Jonckere, O., & Burleigh, S. C. (2021). “Routing in the Space Internet: A Contact Graph Routing Tutorial.” *Journal of Network and Computer Applications* 174: 102884.

Sender	Recvr	From	Until	Range (light seconds)
A	B	1000	1100	1
A	C	1100	1200	30
B	D	1400	1500	120
C	D	1500	1600	90

Figure 3-3: Contact Plan Example: Range Intervals

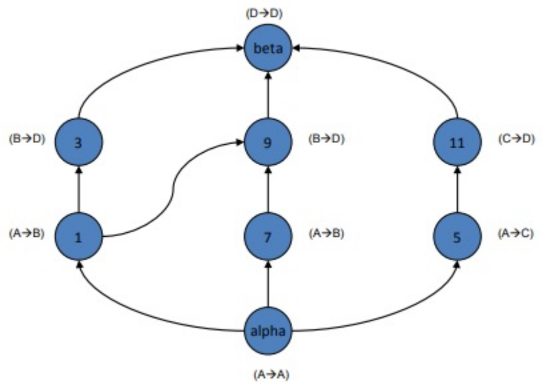
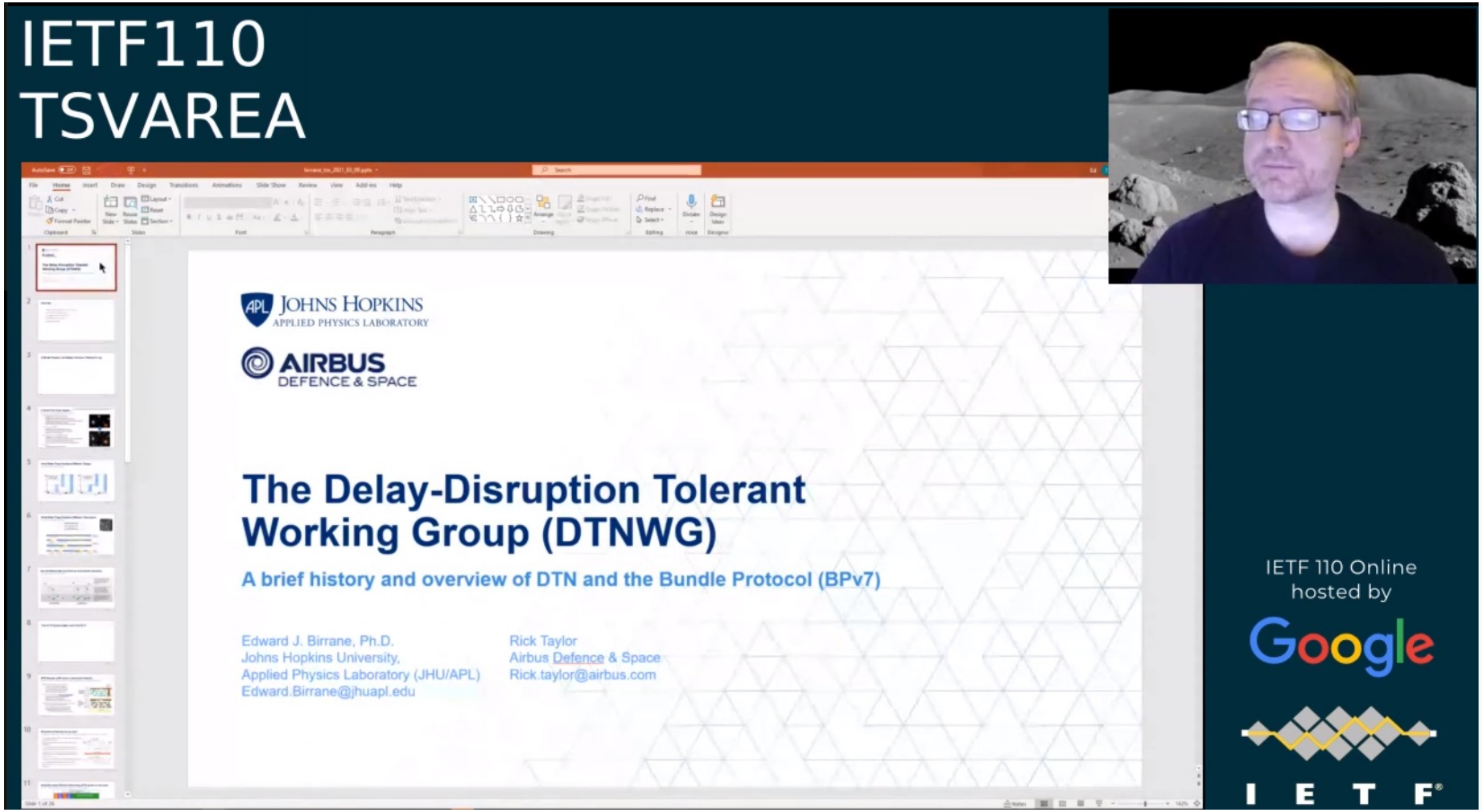


Figure 3-4: Node A’s Contact Graph for Node D, Given This Contact Plan

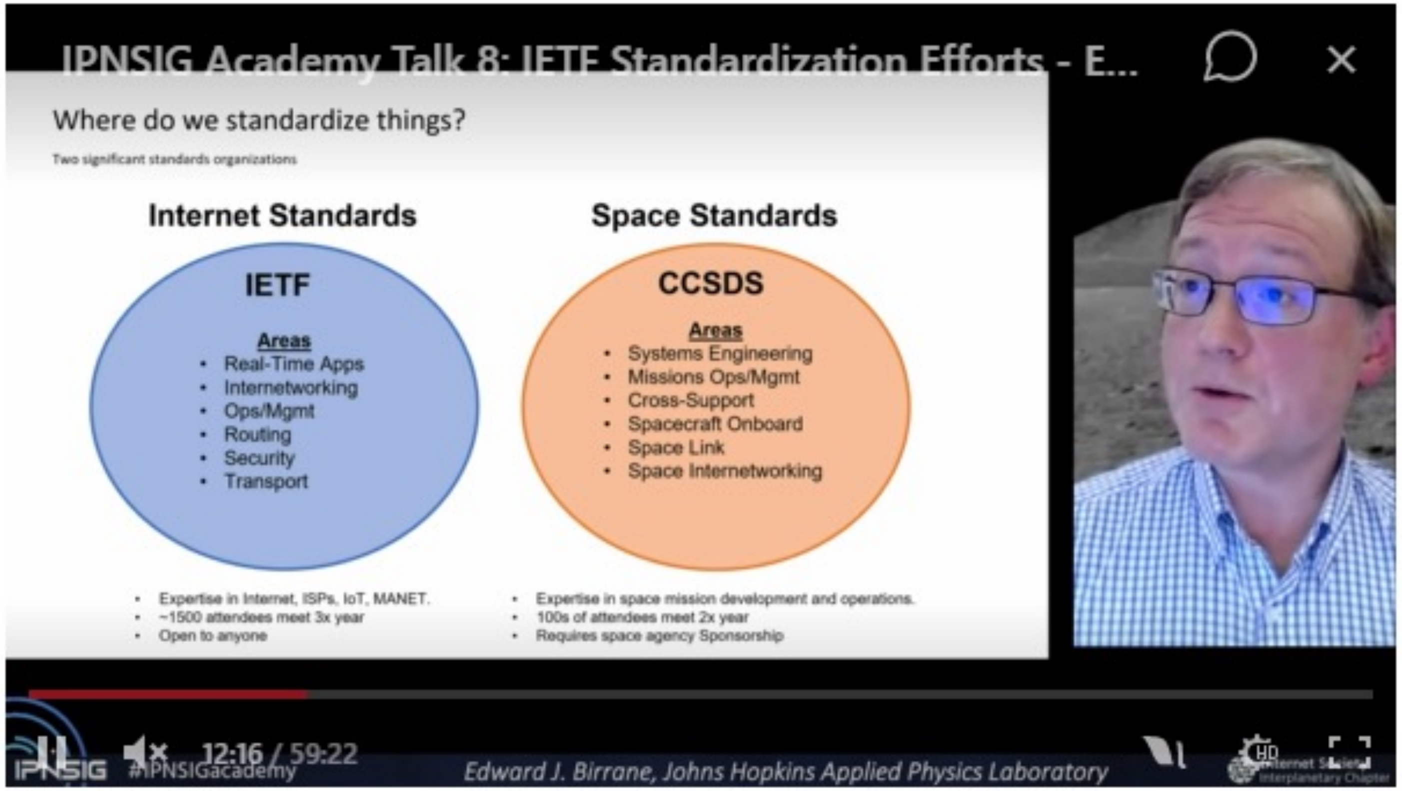
IETF Brief History of DTN

https://youtu.be/xSDxJGdjw98?t=889



IPNSIG Academy

Standardization of DTN in the IETF



IPNSIG Academy – Program for 2022:

1. Yosuke Kaneko	**100+ years vision**
2. Vinton G. Cerf	**DTN Overview**
3. Scott Burleigh	**SSI Architecture study**
4. Oscar Garcia	**DTN Projects Work**
5. Lara Suzuki	**DTN live demonstration**
6. Dave Israel	**NASA Luna Net Overview**
7. David Gomez Otero	**ESA Moonlight Overview**
8. Ed Birrane	**IETF standardization efforts**
9. Keith Scott	**CCSDS standardization efforts**
10. Laura DeNardis	**Internet Governance issues**
11. Scott Pace	**Space Policy, perspective on IPN governance**
12. "IPNSIG Workshop"	**Architecture and Governance of IPN**

https://isoc.live/16141/