



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

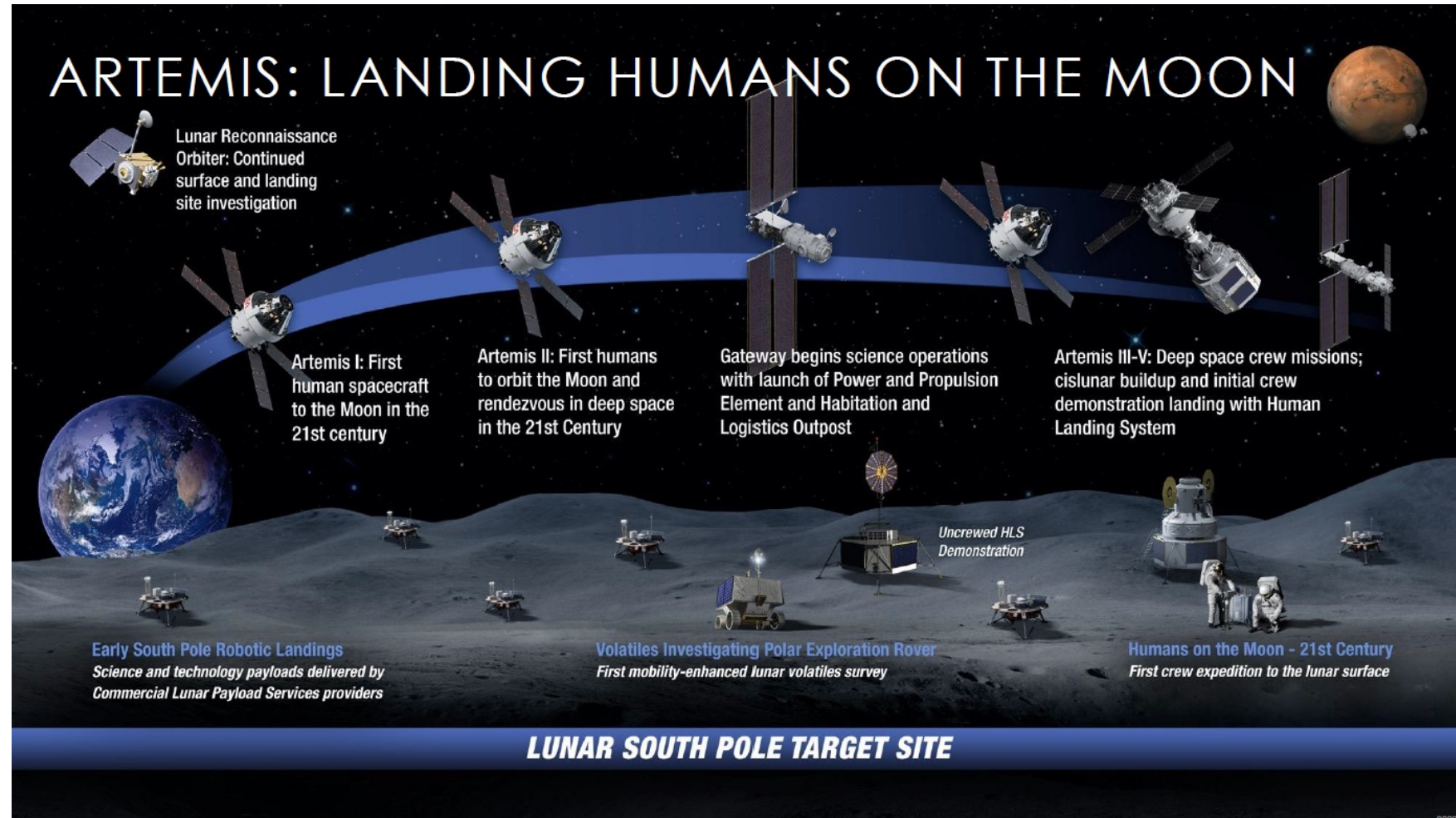
Networks Enable Lunar Exploration

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

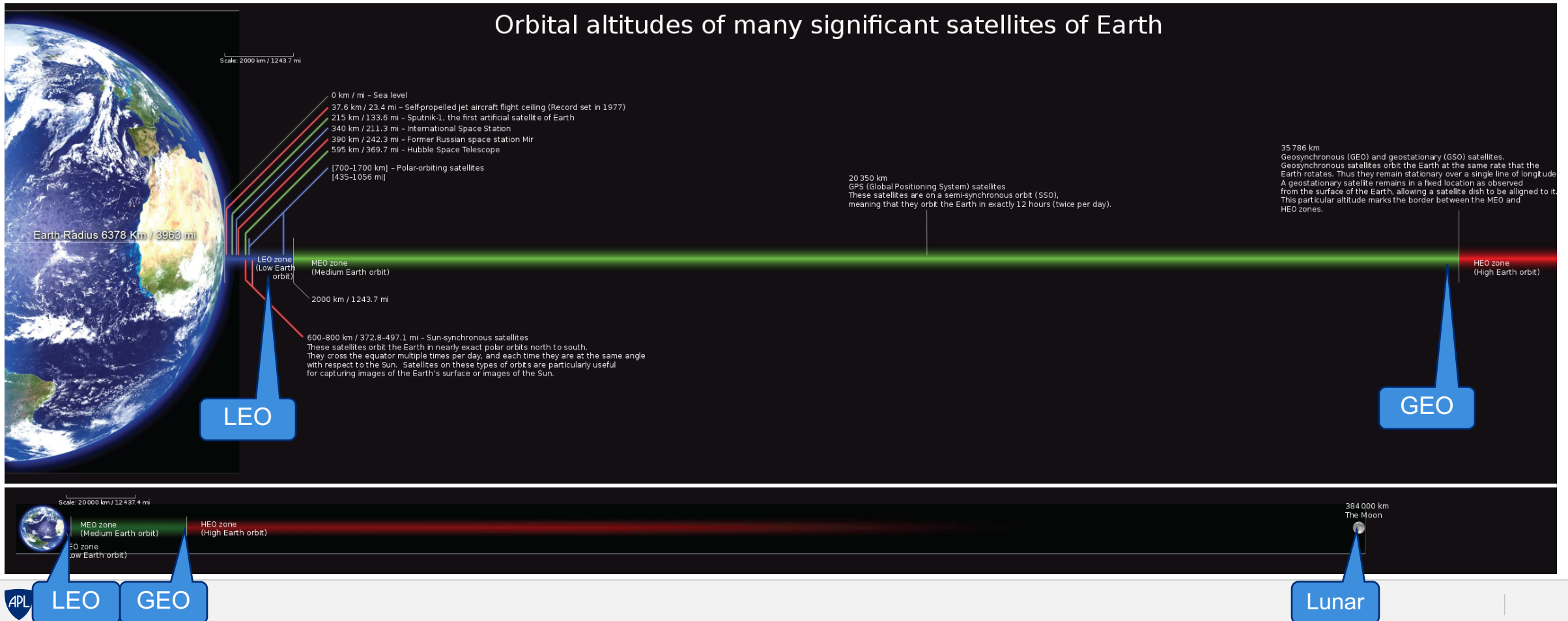
- **Shared Infrastructure**
 - Reduce per-mission costs
 - Broader coverage
 - More & faster paths to Earth
- **Networking Semantics**
 - Resilient path diversity
 - Data security & scalability



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

Orbital altitudes of many significant satellites of Earth



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

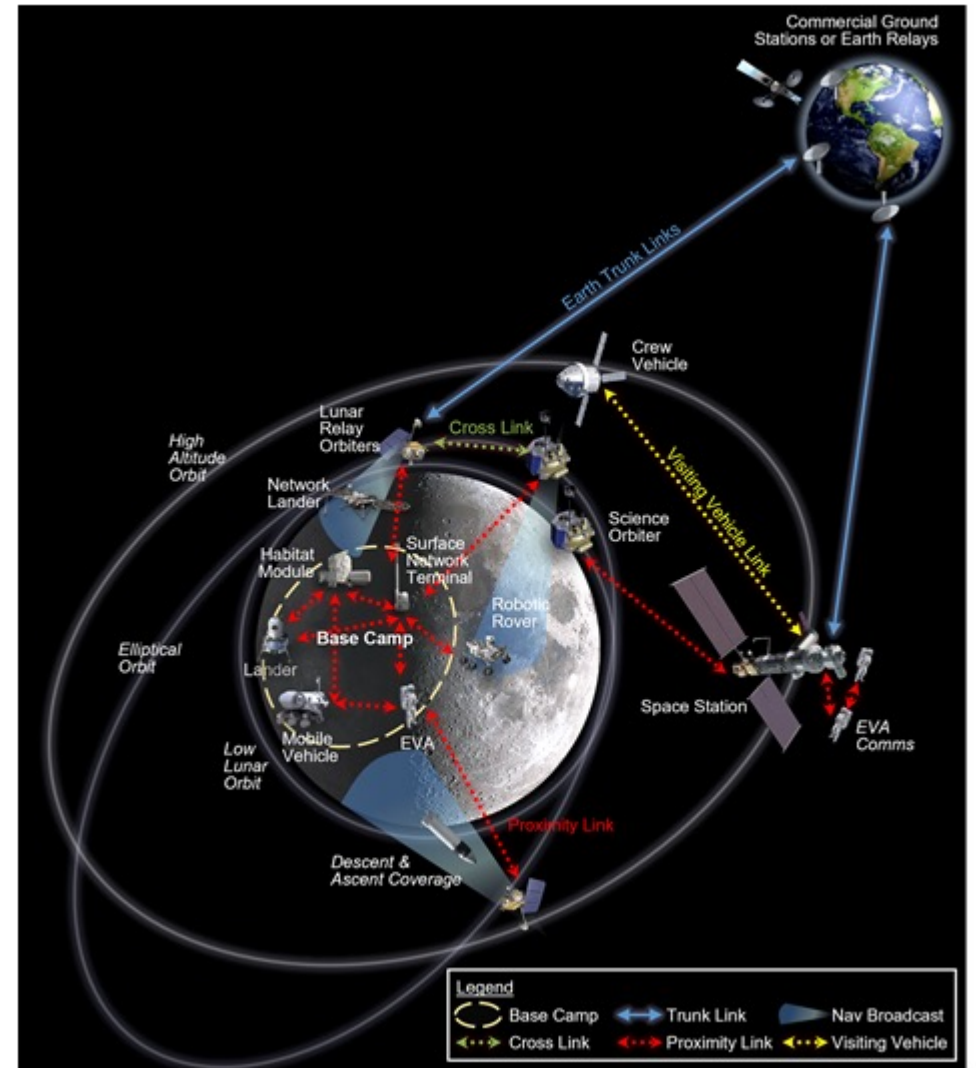
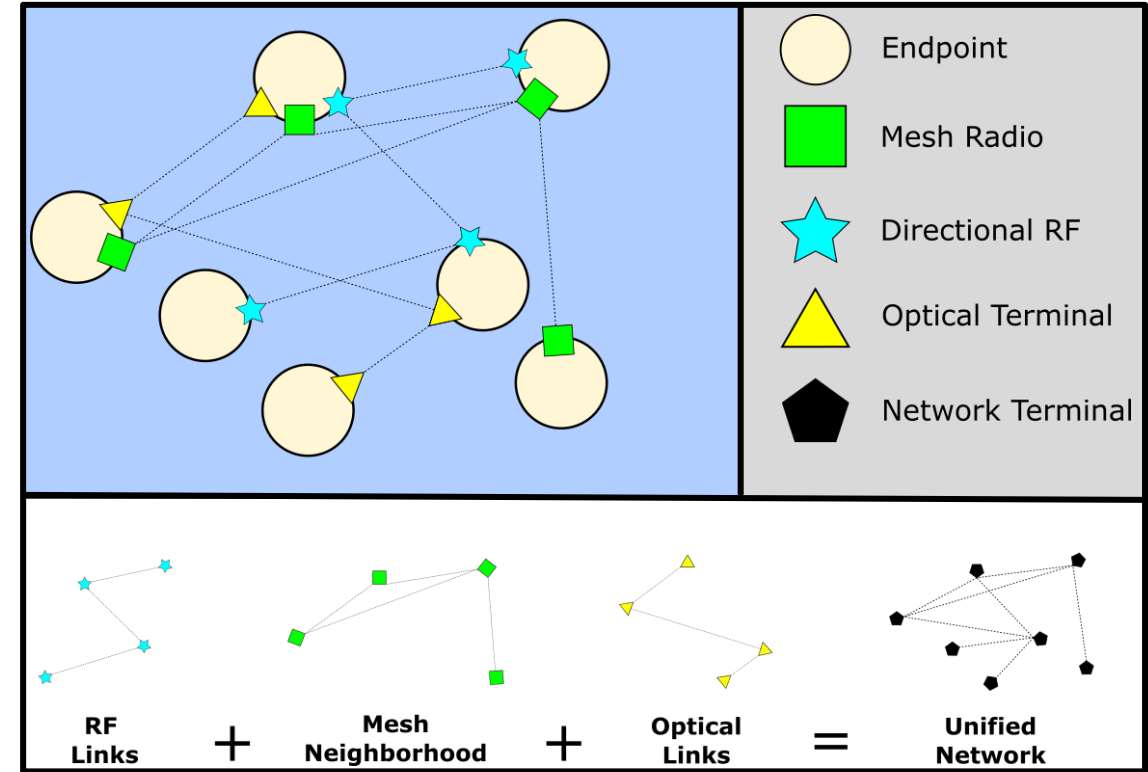


Fig. 1. LunaNet Architecture

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?**

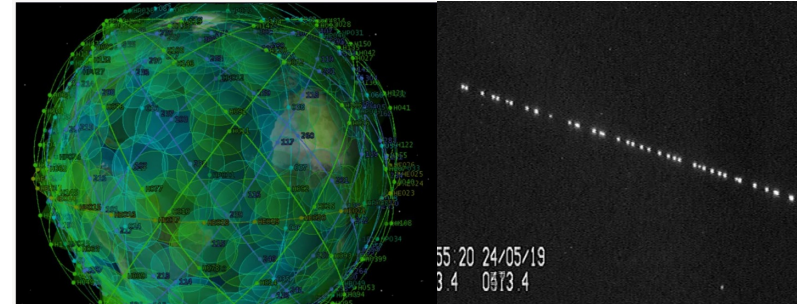
- Identify technology gaps
- Discuss data and control flows
- Understand contributions of vendors\standards
- Recommend on next steps for standards activity
- Avoid local minima (aka... the easy way out)

- **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 2009 to design a National Defense Space Architecture in low Earth orbit. Credit: SDA

There will be links



We have standards

Requirements for the Next Generation Metro & Edge

| | | | |
|---|--|---|---|
| Common Infrastructure Enterprise, Mobility & Residential over the same underlying network | Multi-Layer Convergence Ethernet, IP, and Optical integration over an optimized photonic layer | Disaggregated Principles Solution built from disaggregated components which can be used together or independently | Optimized Routing Specific focus on the future state of Services and Transport including SR and EVPNs |
| End-to-End Automation Closed loop E2E automation leveraging advanced analytics and intelligence | Open APIs Open & standardized models with an emphasis on NETCONF/YANG and gRPC/gNMI | Advanced Visualization Best of class web-based network visualization over the multi-layer infrastructure | Virtualization Support for network virtualization capabilities natively within the solution |

We need much more

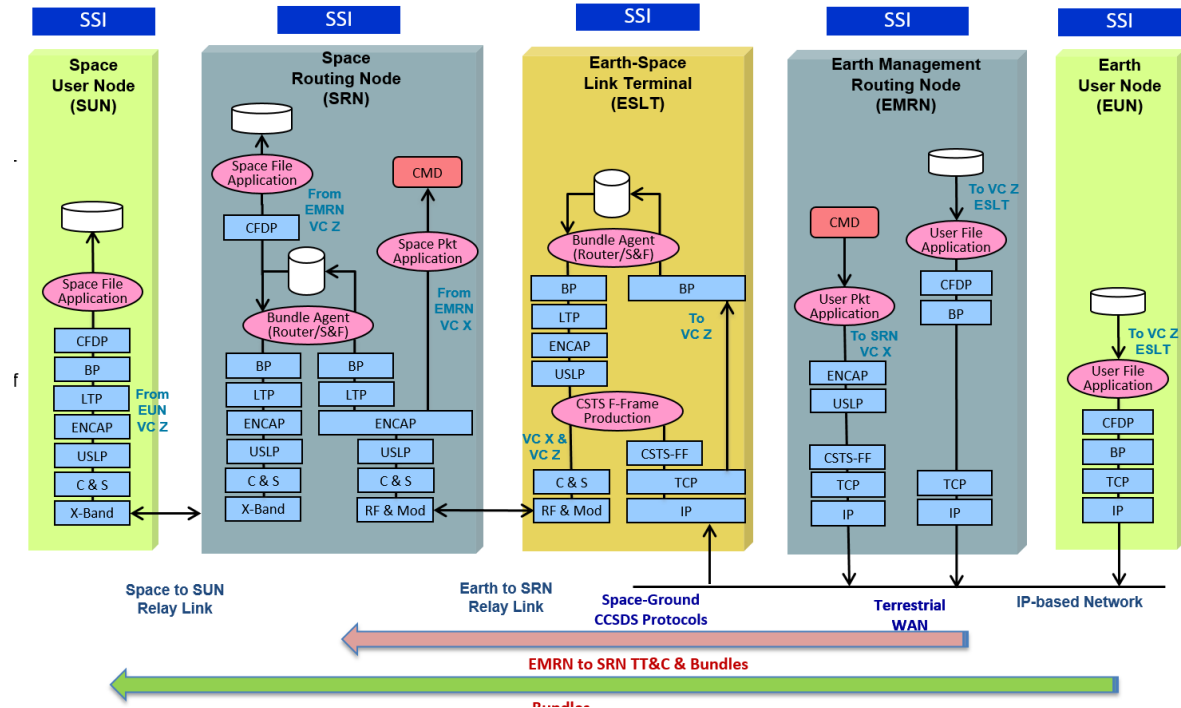
<https://www.ciena.com/insights/articles/how-service-providers-can-win-by-owning-the-edge.html>

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)

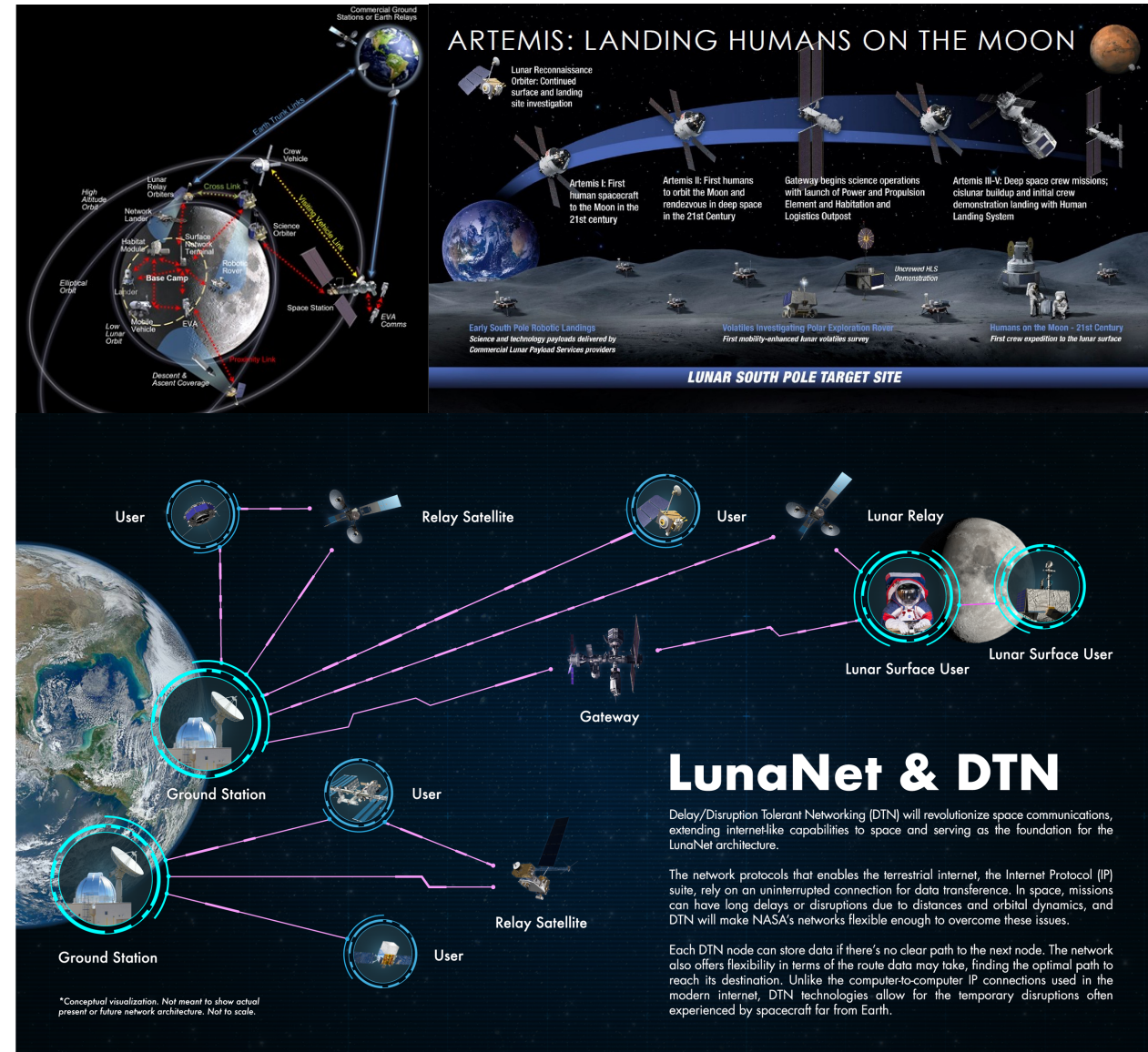


Source: CCSDS, “Space Communications Cross Support Architecture Requirements”, CCSDS 901.1-M-1, dated May 2015

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 |

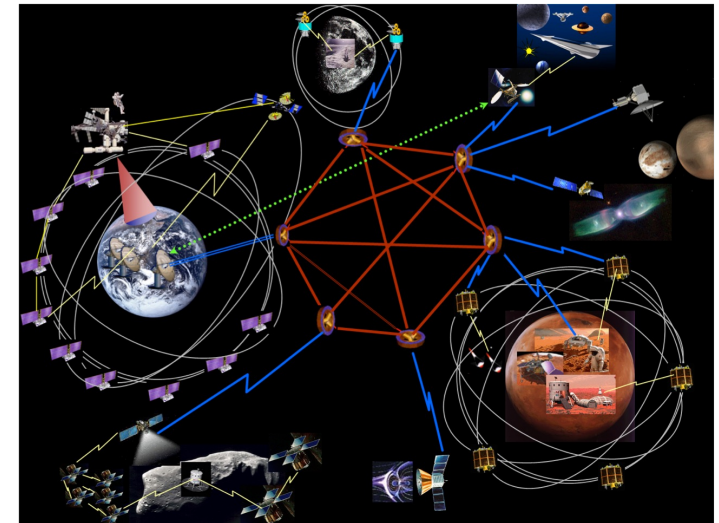
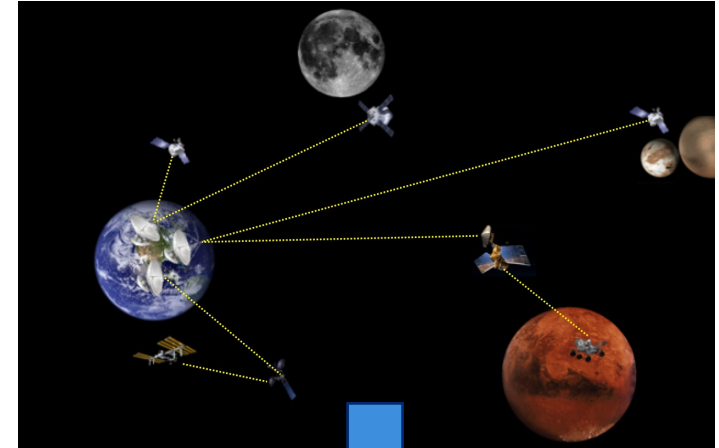
| Challenges to cooperation (co-creation, risk-sharing, pooling & sharing) | |
|--|----------------|
| Governments | Private actors |
| Mutual understanding of expectations and goals | |
| Establishment of appropriate cost and risk-sharing schemes | |
| Change in government priorities and funding | |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



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

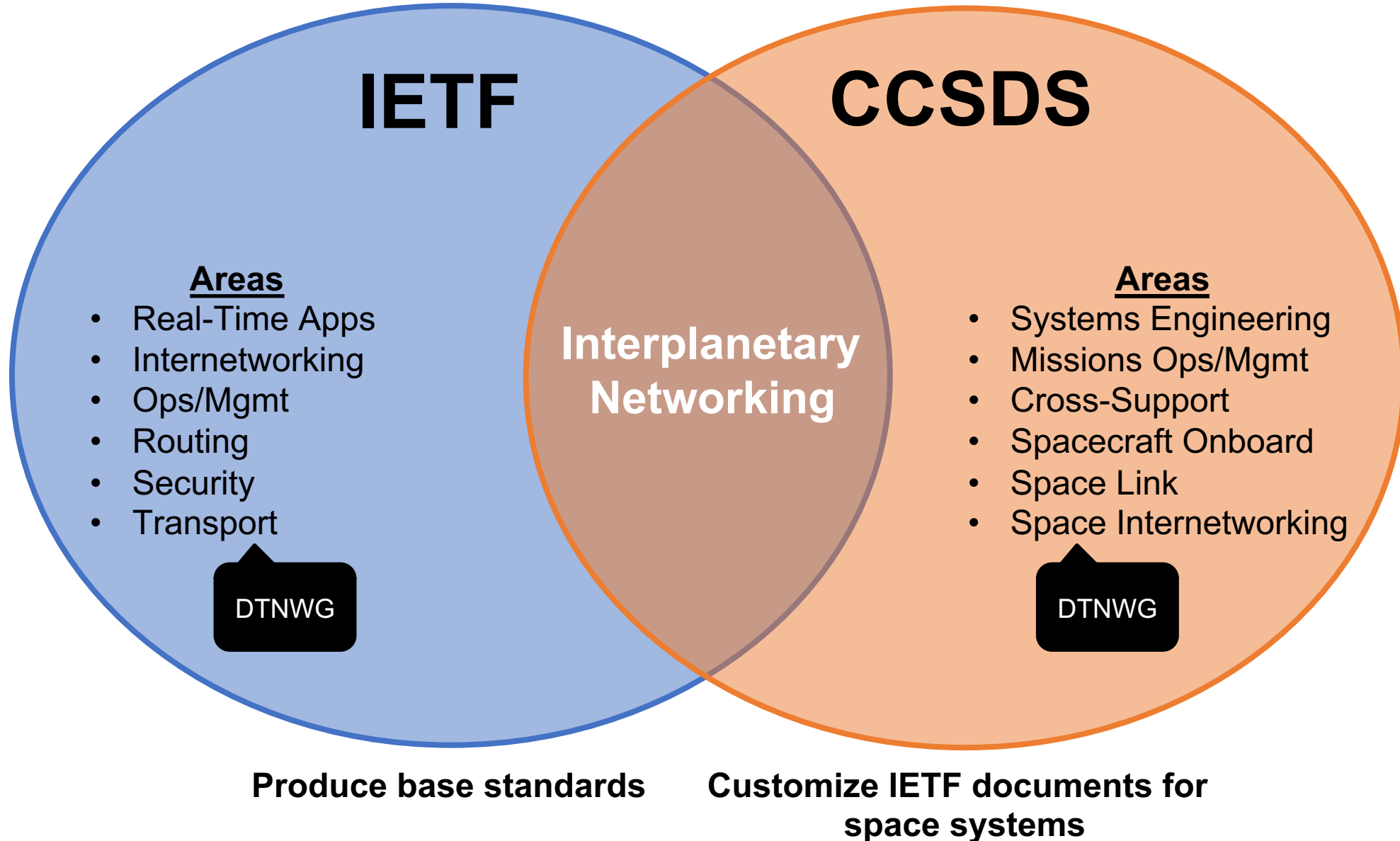
Areas

- 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 DTN WG – How to Participate

- Review online materials
 - DTN WG 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!

Delay/Disruption Tolerant Networking (dtn)

About Documents Meetings History Photos Email expansions List archive »

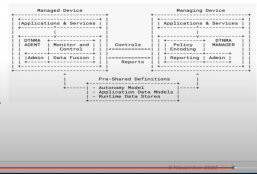
Search

| Document | Date | Status |
|--|---------------------|--|
| Active Internet-Drafts (3 hits) | | |
| draft-ietf-dtn-bpa7-admin-iana-00 | 5 pages 2022-11-07 | I-D Exists WG Document |
| Bundle Protocol Version 7 Administrative Record Types Registry | | |
| draft-ietf-dtn-dtma-03 | 52 pages 2022-10-24 | I-D Exists WG Document |
| DTN Management Architecture | | |
| draft-ietf-dtn-join-update-00 | 22 pages 2022-11-07 | I-D Exists WG Document |
| Update to the ipn URI scheme | | |
| Expired Internet-Drafts (2 hits) | | |
| draft-ietf-dtn-bibect-03 | 14 pages 2020-02-18 | Expired WG Document : Proposed Standard Jul 2023 |
| Bundle-in-Bundle Encapsulation | | |

IETF115 DTN

DTNMA Reference Model
Enabling device self-management

- **Pre-Shared Definitions**
 - Pre-shared data and models.
 - Standardize static data definitions wherever possible.
 - Negotiated during brief periods of connectivity.
- **DTNMA Agent Self-Management**
 - Managed device often disconnected.
 - Local autonomy engine enables self-management.
 - Application of pre-shared policies.
- **Command-Based Management**
 - Cannot perform bulk updates with large data stores.
 - Managing devices instead use a command and control interface.
 - Enables updates to the managed device from
 - Remote managers
 - Local autonomy engine



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1:27:33 / 2:01:54

IETF115-DTN-20221110-1300

About dtn

“This list is for discussions related to the formation of a Delay Tolerant Networking (DTN) working group. The IETF DTN WG research group has worked on the particular protocols and this new activity is targeted towards determining if there is interest in standardizing any output from the DTN WG or other sources.”

To see the collection of prior postings to the list, visit the [dtn Archives](#).

Using dtn

To post a message to all the list members, send email to dtn@ietf.org.

You can subscribe to the list, or change your existing subscription, in the sections below.

Subscribing to dtn

Subscribe to dtn by filling out the following form. You will be sent email requesting confirmation, to prevent others from gratuitously subscribing you. This

Your email address:

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[IETF 116 Yokohama >](#)

IETF 116 starts Saturday 25 March and runs through Friday afternoon, 31 March.

Yokohama, Japan

IETF Standards

APL is authoring networking standards and infusing them into devices

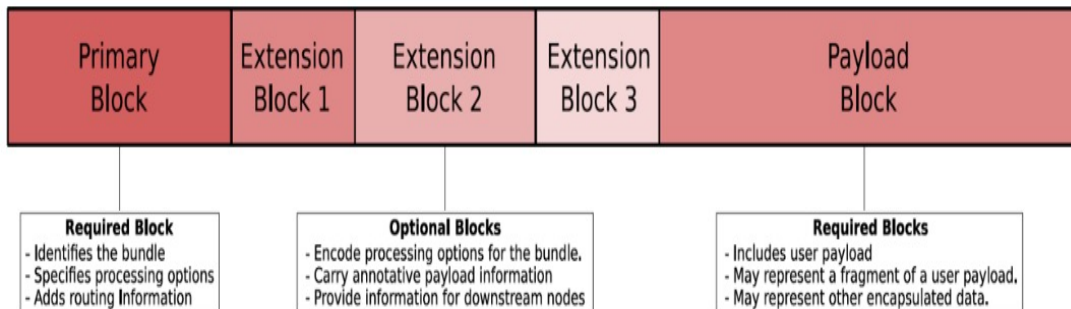
Internet Engineering Task Force (IETF)
Request for Comments: 9171
Category: Standards Track
ISSN: 2070-1721

S. Burleigh
IPNGROUP
K. Fall
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)
Request for Comments: 9172
Category: Standards Track
ISSN: 2070-1721

E. Birrane, III
K. McKeever
JHU/APL
January 2022

Bundle Protocol Security (BPsec)

Abstract

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

Similar to the encapsulation approach, augmentation is a mixture of both benefits and challenges.

4.5.2.1 Benefits
Using information augmentation to scope DTN security operations has two compelling benefits: resilience and diversity.

4.5.2.1.1 Security Resilience The overscoping of security services that can occur with encapsulation leads to a more fragile security system. Secure operations can be made more resilient by focusing them only on the blocks within a bundle that need to be secured.
This does not mean that, overall, less security is available to a bundle. Instead, it means that multiple invocations of a security mechanism run over individual extension blocks provide a granularity that allows security to be targeted for the type of block being secured.

4.5.2.1.2 Security Diversity Diversity here means that different security operations can be applied to different blocks within the bundle. Representing a diverse set of security options allows different security mechanisms to receive different security mechanisms.

Figure 4.6 illustrates a case where there exist multiple extension blocks in a bundle, where some blocks require authentication only and others require confidentiality. Different security services might use different cipher suites, or similar cipher suites and different keys. Overall, this figure shows two main types of diversity for security in a bundle:

- Different Security Algorithms:** Different extension blocks may have different security services applied to them.
- Multiple Security Results:** Even amongst the set of extension blocks receiving the same security service, capturing individual security results allows different BPAs in the network to process these services as needed.

Figure 4.6 BPsec enables security diversity within a bundle. Different security algorithms can be

4 The BPsec Security Mechanism

Figure 4.8 A BCB block replaces the plaintext of its target block with ciphertext. BCB blocks contain some of the inputs to, and outputs of, a security context implementation.

The In-Confidentiality service is complex because it changes its target block. Additionally, because the service is authenticated confidentiality, an authentication mechanism is calculated over the ciphertext and the result of this mechanism may be either included in the BCB or coupled with the ciphertext placed in the target block.

6.6.1 Populating the ASB
In this way, the population of the BCB is similar to the population of the ASB, with the exception that the BCB also changes the security target block type-specific data field.
The population of the BCB block is illustrated in Figure 6.8. In this illustration, a security target block has its block-type-specific data field replaced with ciphertext composed by a security context. Additionally, the BCB holds any additional integrity mechanisms in a security result (SR) held in the BCB block itself. The parameters used by the security context are placed in the abstract block information section of the BCB, and the block number of the target block is stored in the security target array (TA).

6.6.2 Block Considerations
Block processing considerations when constructing a BCB are similar to those when constructing a ASB, with two notable exceptions relating to fragmentation and BCB processing.

Securing Delay-Tolerant Networks with BPsec
Dr Edward J. Birrane III
Sarah Heiner
Ken McKeever
WILEY

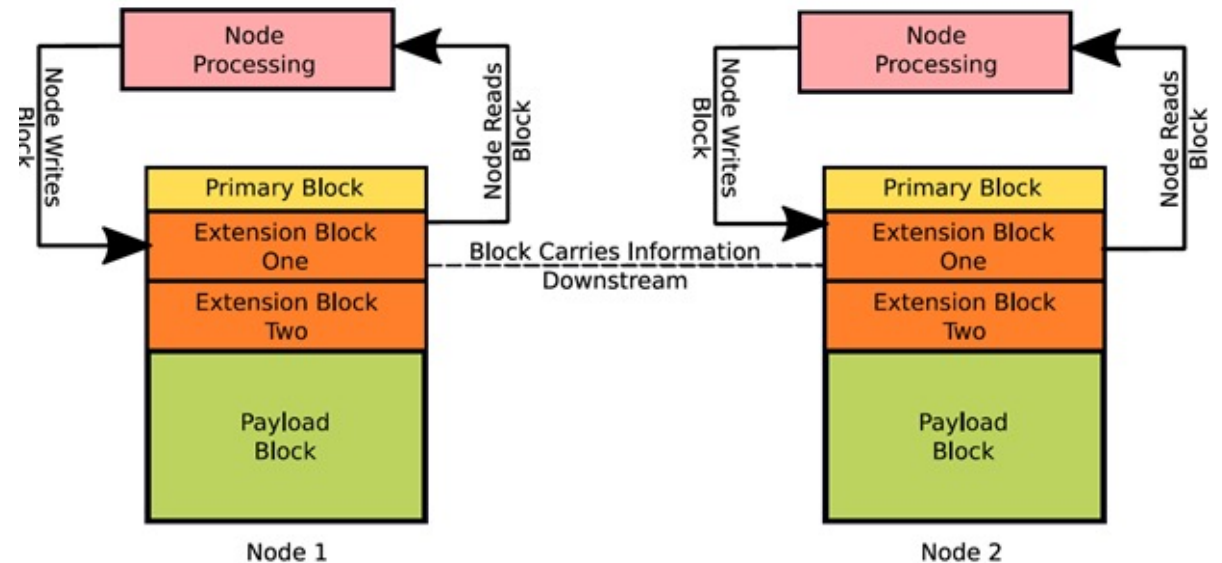
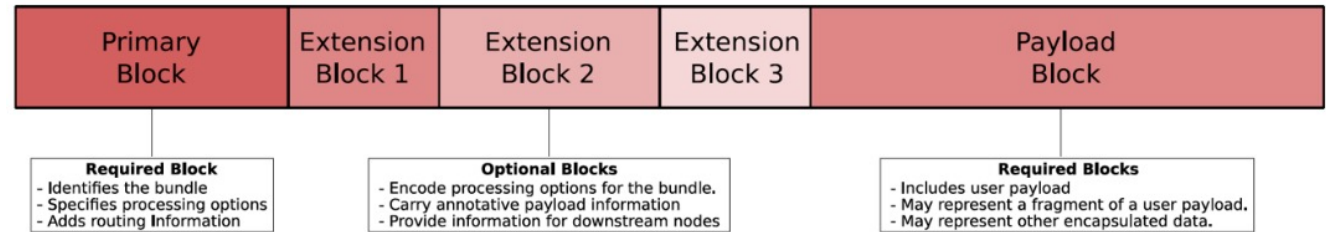
Spotlight Technology: BPv7 (RFC9171)

- 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...



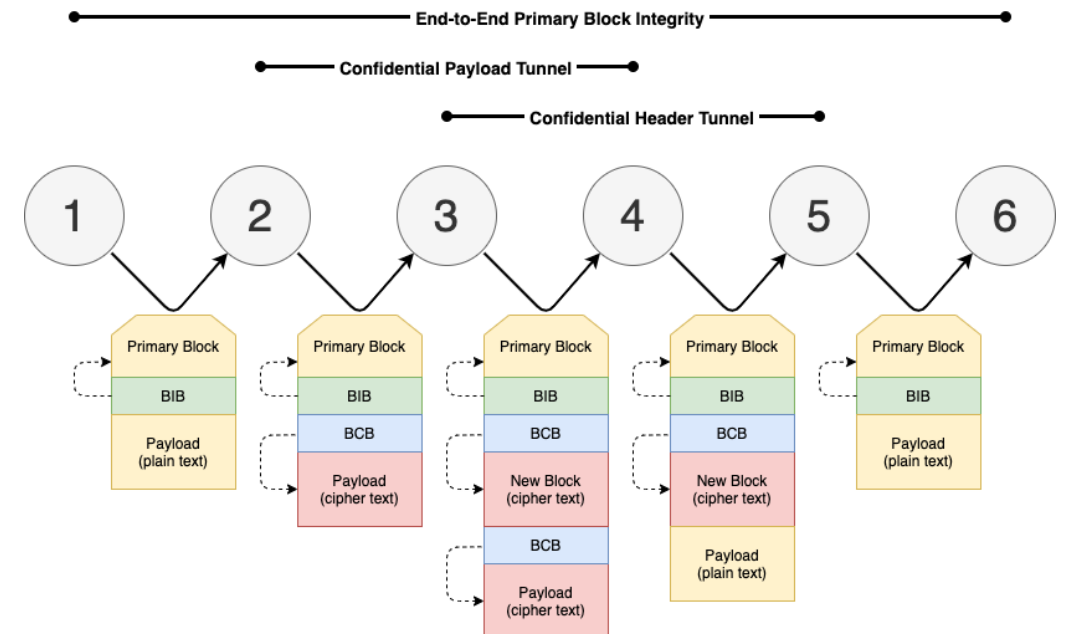
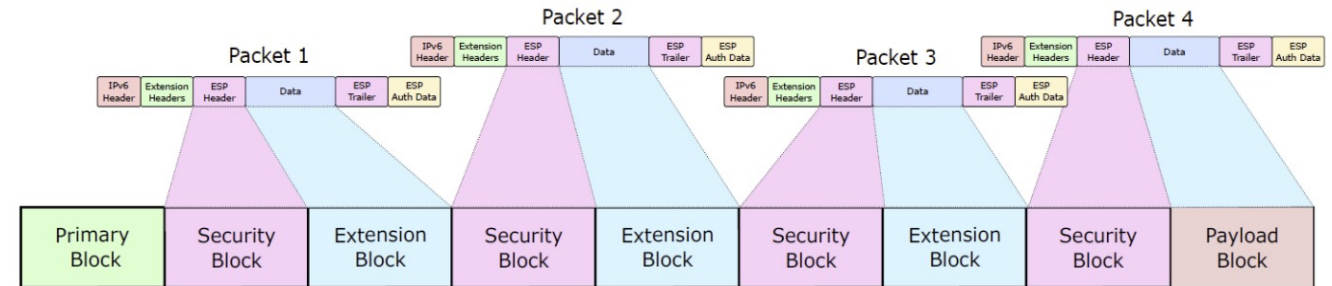
Spotlight Technology: BPsec (RFC9172)

• What is BPsec?

- Security extensions for BPv7
- Block-by-block security
 - Not whole-PDU security

• Benefits

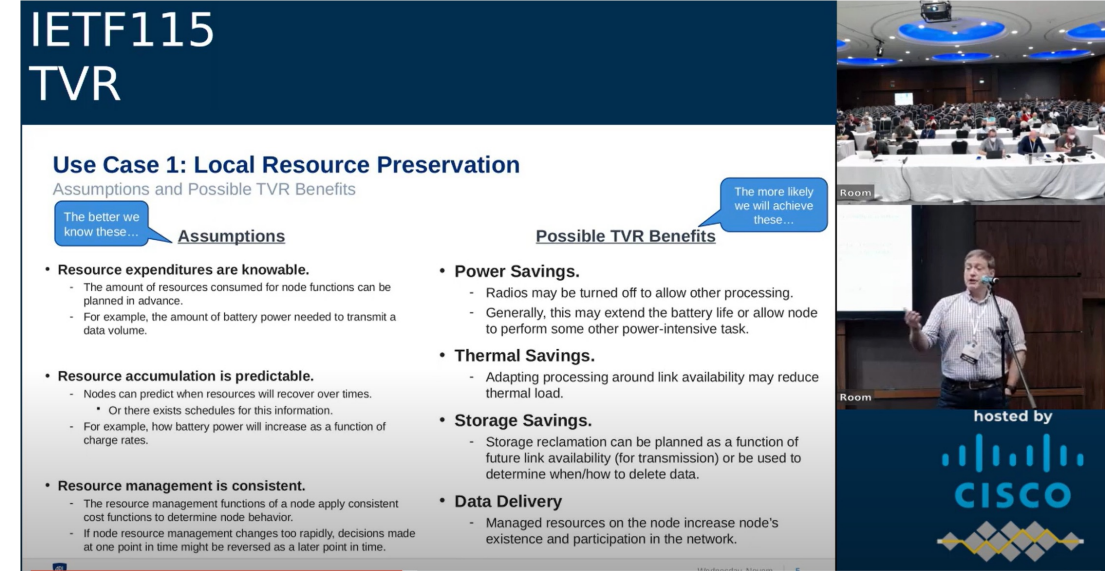
- Multiple annotations in a “bundle” may be secured separately.
 - Encrypt a payload
 - Sign a header
- Allows secured block manipulation
 - Adding a secured block to a bundle at a waypoint.
 - Building overlapping security tunnels.
- Possibly useful for data aggregation
 - Aggregate data flows into 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.



IETF115 TVR

Use Case 1: Local Resource Preservation
Assumptions and Possible TVR Benefits

Assumptions (The better we know these...)

- **Resource expenditures are knowable.**
 - The amount of resources consumed for node functions can be planned in advance.
 - For example, the amount of battery power needed to transmit a data volume.
- **Resource accumulation is predictable.**
 - Nodes can predict when resources will recover over times.
 - * Or there exists schedules for this information.
 - For example, how battery power will increase as a function of charge rates.
- **Resource management is consistent.**
 - The resource management functions of a node apply consistent cost functions to determine node behavior.
 - If node resource management changes too rapidly, decisions made at one point in time might be reversed as a later point in time.

Possible TVR Benefits (The more likely we will achieve these...)

- **Power Savings.**
 - Radios may be turned off to allow other processing.
 - Generally, this may extend the battery life or allow node to perform some other power-intensive task.
- **Thermal Savings.**
 - Adapting processing around link availability may reduce thermal load.
- **Storage Savings.**
 - Storage reclamation can be planned as a function of future link availability (for transmission) or be used to determine when/how to delete data.
- **Data Delivery**
 - Managed resources on the node increase node's existence and participation in the network.

hosted by **CISCO**

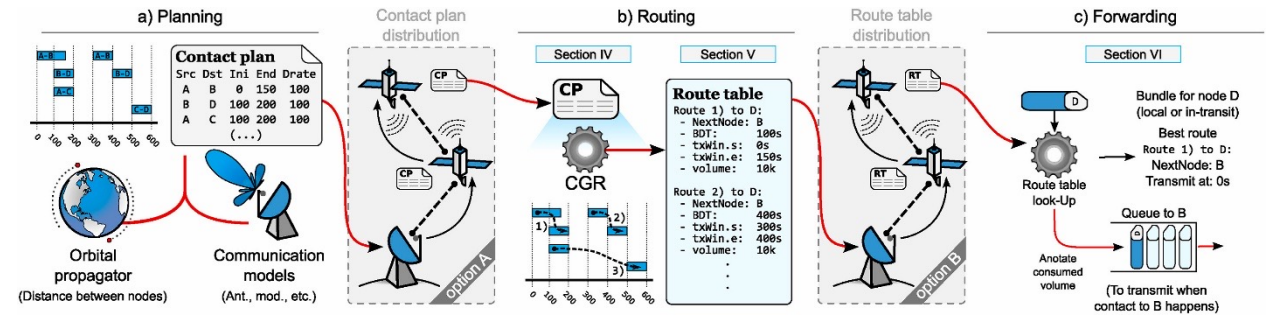
Spotlight Technology: CGR/SABR

- 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 | Recv | 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

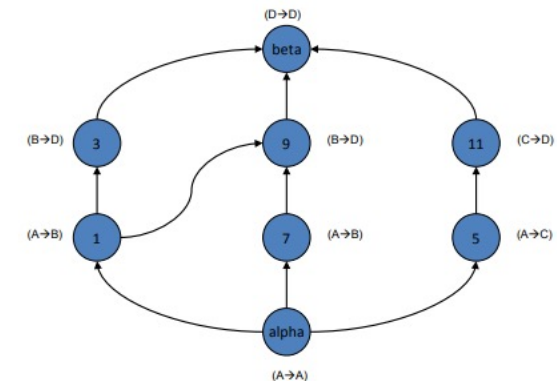
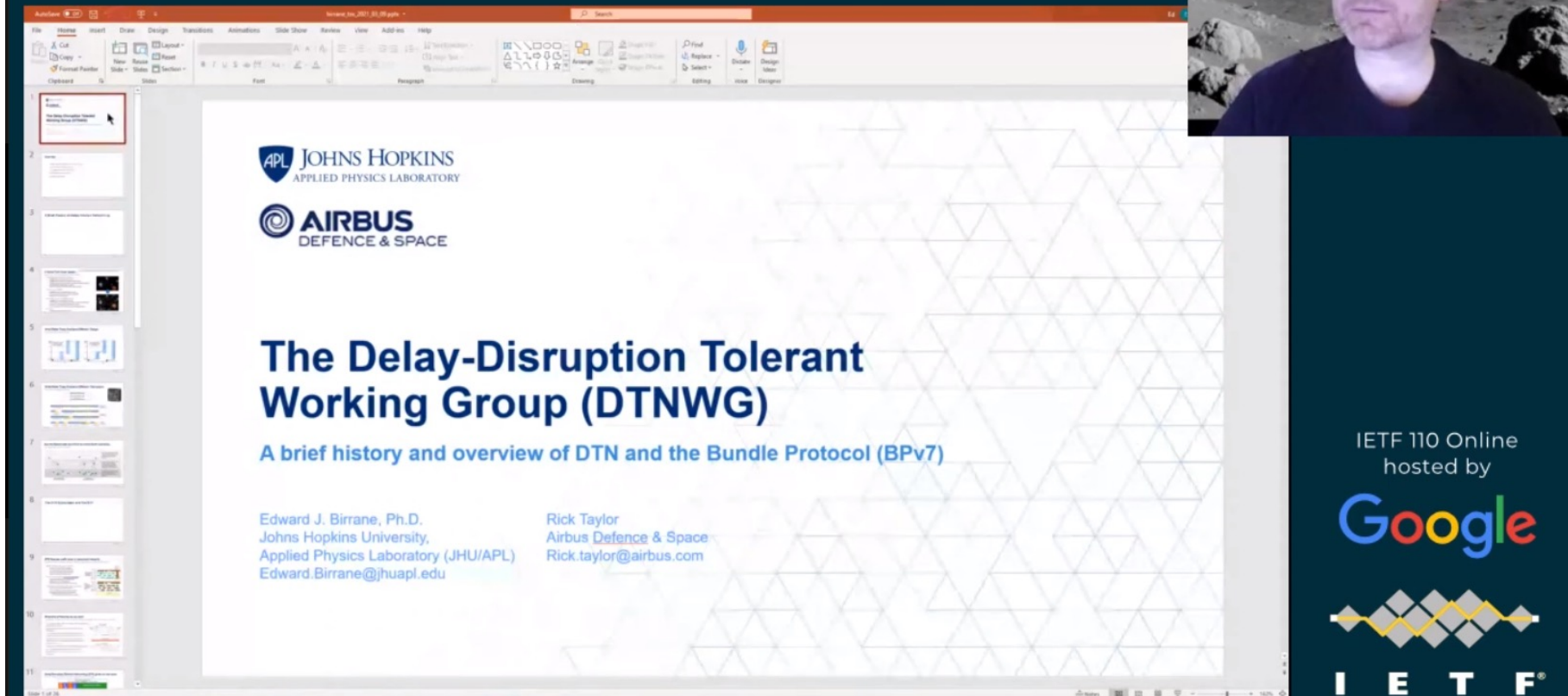


Figure 3-4: Node A's Contact Graph for Node D, Given This Contact Plan

IETF Brief History of DTN

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

IETF110 TSVAREA



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AIRBUS
DEFENCE & SPACE

The Delay-Disruption Tolerant Working Group (DTN WG)

A brief history and overview of DTN and the Bundle Protocol (BPv7)

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

Rick Taylor
Airbus Defence & Space
Rick.taylor@airbus.com

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I E T F

IPNSIG Academy

Standardization of DTN in the IETF



IPNSIG Academy Talk #8
'IETF Standardization Efforts'
December 7 2022

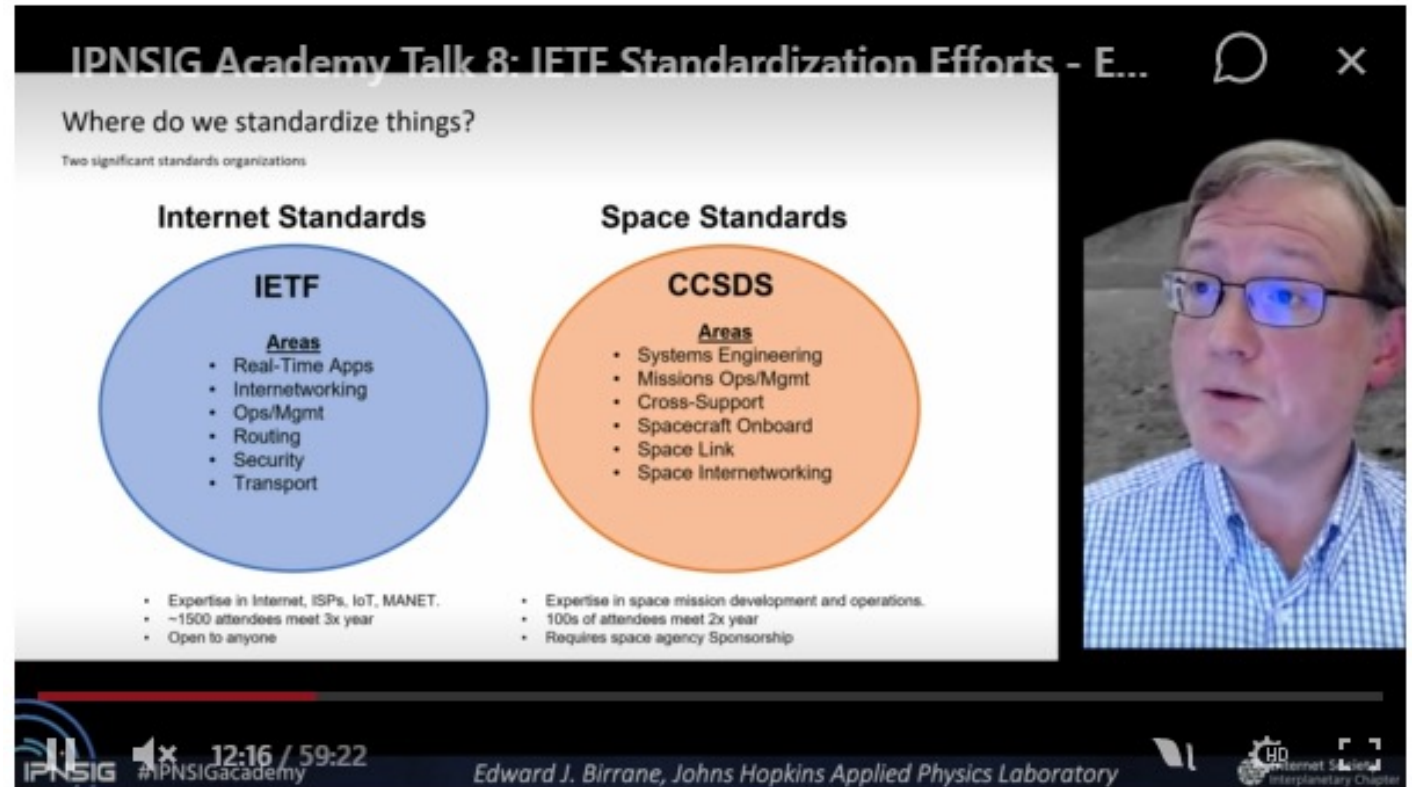
Internet Society
Interplanetary
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9. Keith Scott
10. Laura DeNardis
11. Scott Pace
12. "IPNSIG Workshop"

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 Policy, perspective on IPN governance
Architecture and Governance of IPN



IPNSIG Academy Talk 8: IETF Standardization Efforts - E...

Where do we standardize things?
Two significant standards organizations

| Internet Standards | Space Standards |
|--|--|
| IETF Areas <ul style="list-style-type: none">• Real-Time Apps• Internetworking• Ops/Mgmt• Routing• Security• Transport | CCSDS Areas <ul style="list-style-type: none">• Systems Engineering• Missions Ops/Mgmt• Cross-Support• Spacecraft Onboard• Space Link• Space Internetworking |
| <ul style="list-style-type: none">• Expertise in Internet, ISPs, IoT, MANET.• ~1500 attendees meet 3x year• Open to anyone | <ul style="list-style-type: none">• Expertise in space mission development and operations.• 100s of attendees meet 2x year• Requires space agency Sponsorship |

Edward J. Birrane, Johns Hopkins Applied Physics Laboratory

<https://isoc.live/16141/>